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(Now entitled Journal of Geophysical Research)

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Atmospheric Electricity

VOLUME XXVII MARCH-JUNE, 1922 Nos. 1 and 2

SOME RESULTS OF RECENT EARTH-CURRENT OBSERVATIONS AND RELATIONS WITH SOLAR ACTIVITY, TERRESTRIAL MAGNETISM, AND ATMOSPHERIC ELECTRICITY.[1]

BY LOUIS A. BAUER.

1. Renewed interest was aroused by the remarkable earth-current disturbances of May 14 to May 20, 1921, and, as will be recalled, there were also at the time brilliant displays of polar lights, severe magnetic storms, and manifestations of pronounced solar activity. These disturbances and accompanying phenomena occurred over the entire Earth. Northern lights were observed in lower northerly latitudes than usual, and southern lights were seen as far north in the Southern Hemisphere as Apia, Samoa—a very unusual occurrence. In certain respects the disturbances, during the period mentioned, were similar to those which occurred August 29 to September 4, 1859. In the latter case, northern lights were visible as low as 18° North, and the magnetic disturbances were of almost unexampled size and rapidity, the accompanying aurora being extraordinarily brilliant and potential differences of 700 to 800 volts are said to have been reached on telegraph lines for distances of 500 to 600 kilometers.

2. Since Oersted's discovery, somewhat over a century ago, of the deflection of a compass needle by an electric current, hypotheses have been repeatedly advanced that the Earth's magnetic field is caused by electric currents circulating in the crust. However, most of the earth-current observations up to the present time indicate that the constant part of the electric current along a parallel of latitude is chiefly towards the east, instead of towards the west, as would be necessary to account for the observed phenomena of the magnetic needle.

3. At the International Electric Congress, held at Paris in 1881, such interest was aroused in the subject that systematic

[1] Presented before the Philosophical Society of Washington, February 25, 1922.

investigation of earth-currents, especially as observed in telegraph lines, was undertaken in various countries. Thus material was furnished for Weinstein's well-known publication[2] in which data obtained on two telegraph lines (Berlin to Thorn, 262 kilometers, and Berlin to Dresden, 120 kilometers), for four complete years, namely, from 1884 to 1887, were successfully utilized.

4. Unfortunately, the interest then aroused has waned and, as far as known, there has been but one observatory in recent years where systematic earth-current observations have been made, namely, at the Observatorio del Ebro, Tortosa, Spain, where a very valuable series has been obtained from 1910-1920.[3] May renewed interest be aroused in this important subject at the forthcoming Rome meeting of the International Geodetic and Geophysical Union!

5. The Department of Terrestrial Magnetism is planning to install earth-current lines for systematic observations at its magnetic observatories. This year such lines are to be installed at the Department's observatory at Watheroo, Western Australia, and in the following year at the Huancayo Observatory, Peru. The Commonwealth of Western Australia, besides making three Crown Grants, aggregating 200 acres, for the site of the Watheroo Observatory, furthermore has granted use by the Carnegie Institution of Washington, for purposes of earth-current investigations, of two 10-mile strips of land, each 1 rod wide, one of them running astronomically north and south and the other, astronomically east and west; these two strips of land start from the observatory-site and terminate each in a 10-acre tract.

6. Various initial investigations have been in progress at the Department's laboratory.[4] To Mr. O. H. Gish, appointed January 1, 1922, Associate Physicist of the Department, has been assigned the continuation of these investigations. Furthermore, in order to take advantage of the previous experience gained in such work, and to ascertain the direction in which further study is desirable, a discussion of the available data, especially for the 11-year series at the Observatorio del Ebro, was undertaken by the writer. The chief results of this latter study are here presented.

[2] *Weinstein, B.*: Die Erdströme im Deutschen Reichstelegraphengebiet und ihr Zusammenhang mit den Erdmagnetischen Erscheinungen. Mit einen Atlas. Braunschweig, 1900.

[3] Unfortunately the series was interrupted on January 1, 1921, because of defective earth-plates; it is much hoped that the defects will soon be remedied and the series continued.

[4] See *Terr. Mag.*, vol. 23, 1918, pp. 73-91 for a preliminary report by Dr. S. J. Mauchly, entitled, "A Study of Pressure and Temperature Effects in Earth-Current Measurements." (See also the article by J. E. Burbank, "Earth-Currents, and a Proposed Method for their Investigation;" *Terr. Mag.*, vol. 10, 1905, pp. 23-49.)

Earth-current Observations at the Observatorio del Ebro, 1910-1920.

7. Earth-current measurements have been made at the Observatorio del Ebro since January, 1910, along two lines, called here *N'S'* and *W'E'*, respectively. For brevity, the observatory will hereafter be designated "Ebro" merely. The pertinent data for these lines are given in Table 1, from which it will be seen that

TABLE 1.—*Pertinent data respecting earth-current lines at the Ebro Observatory.*

	N'S'	W'E'	
	1910-1920	1910-1911 (Jan.)	1911 (Feb.)-1920
Direction of line (from true North)	25° 16′ W	112° 37′ W	114° 46′ W
Distance between terminal plates	1,280 meters	1,420 meters	1,415 meters
Difference in level of terminal plates	8.8 "	6.8 "	6.8 "

they are each somewhat over a kilometer long, the angle between them being 87° 21′ during the period from January, 1910, through January, 1911; a change was then made in the W′E′ line so that the angle between the lines closely approached 90°, namely, 89° 30′. For details respecting the installations, methods of observation, photographic registration, and evaluation of the electrograms, reference will have to be made to the various observatory publications.[5] The earth-plates were connected by aerial lines.

The *geographic position* of the Ebro Observatory is 40° 49′ N, and 0° 31′ E; accordingly G. M. T. hours are within two minutes of local hours. The *altitude above sea-level* is 51 meters.

8. Starting with Father Ubach's formulæ,[6] we have reduced for the period investigated the earth-current results, as published in the observatory bulletins, so that they would apply to the astronomical directions. For the five-year period 1914-1918, there will be found in these valuable bulletins corresponding magnetic and earth-current data for the 5 so-called "international magnetically-calm days" per month. In general, the earth-currents were comparatively undisturbed on these magnetically-quiet days, though in a few instances, it was necessary to utilize also the data on days marked in the Observatory publications as

[5] *Cf.* Article by José Ubach, S. J., Boletin mensual del Observatorio del Ebro, Tortosa, vol. 1, No. 1., Jan., 1910, pp. 51-55, and Mémoires de l'Obs. de l'Ebre. No. 4, La Section Eléctrique, par J. García Mollá, S. J., 1910, pp. 95-119.

[6] *l. c.*, pp. 51-55.

"electrically-calm." These cases were in July, 1916, and February, 1918, for the $N'S'$ currents, and in June, 1915, and January, 1916, for the W'E' currents. Account was also taken of some obvious typographical errors.

9. If $N'S'$ and $W'E'$ represent, respectively, the currents corresponding to the measured potential-differences in millivolts per kilometer, along the directions given in Table 1, and NS and WE, the currents along the astronomical directions, then we have for the period 1911 (Feb.)-1920:

$$NS = 0.908\ N'S' - 0.427\ W'E' = -N \qquad (1)$$
$$WE = 0.419\ N'S' + 0.904\ W'E' = -W \qquad (2)$$
$$R = \sqrt{(NS)^2 + (WE)^2} = \sqrt{(-N)^2 + (-W)^2} \qquad (3)$$
$$A = \tan^{-1}(WE)/(NS) = \tan^{-1}(-W)/(-N) \qquad (4)$$

The values of the quantities computed from the published data, with the aid of these formulæ, are given in Tables 2, 3 and 4. *The directions of the rectangular components of the observed currents are found to be from N to S and W to E.*

10. To facilitate the investigation of the relations between electric and magnetic effects, the signs adopted in this paper are in accordance with the following conventions: Magnetic component (X), along a meridian, being taken positive towards true North, implies that electric component (W), perpendicular to X (hence, along parallel of latitude), shall be taken positive towards true West; magnetic component (Y), along a parallel of latitude, being taken positive towards true East implies that electric component (N), perpendicular to Y (hence, along a meridian), shall be positive towards true North. Accordingly, *minus values of N mean that the meridional component of the observed earth-current flows from north to south, and a minus value of W means that the latitudinal component of the observed earth-current flows from west to east.* The following additional symbols are used: D for magnetic declination; I for magnetic inclination; H for horizontal intensity; Z for vertical intensity (taken positive vertically downwards), and F for total intensity. The magnetic components are expressed in terms of $\gamma = 0.00001$ C. G. S., and the earth-current data in millivolts per kilometer, designated by $v/k = 0.001\ V/k$ (volts per km.). Tables 2-5 give the electric and magnetic data for the 5 years, 1914-1918.

TABLE 2.—*Mean data for the magnetic elements and for the earth currents at the Ebro Observatory for the magnetically-quiet days, 1914-1918.*

Earth-Current Data				Magnetic Data						
−N	−W	R	A	D	I	H	X	−Y	Z	F
v/k	v/k	v/k	°	° ′	° ′	γ	γ	γ	γ	γ
204.4	113.8	233.9	29.1 (E of S)	12 34.6W	57 45.6	23295	22737	5073	36935	43670

TABLE 3.—*Monthly and annual values of components of earth-current data at the Ebro Observatory for the magnetically-calm days, 1914-1918, in millivolts per kilometer.*

Month	−N, or Component N to S						−W, or Component W to E					
	1914	1915	1916	1917	1918	Mean	1914	1915	1916	1917	1918	Mean
	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k
Jan.	522	239	103	162	28	211	264	133	71	96	37	120
Feb.	493	273	313	124	113	263	254	148	173	78	67	144
Mar.	525	311	274	234	117	292	264	161	146	121	69	152
Apr.	491	356	293	283	203	325	252	179	151	140	104	165
May	482	264	454	295	239	347	239	171	219	134	120	177
Jun.	525	78	471	365	354	358	248	144	225	169	165	190
Jul.	549	299	313	443	406	402	269	137	152	204	188	190
Aug.	48	449	11	37	4	110	44	215	24	27	10	64
Sep.	12	11	−2	−2	−5	3	27	31	25	19	12	23
Oct.	0	102	−5	−1	−4	18	32	80	25	26	16	36
Nov.	5	196	−7	−4	38	46	26	121	24	25	35	46
Dec.	137	62	16	37	136	78	84	55	32	41	81	59
Mean	316	220	186	164	136	204	167	131	106	90	75	114

Magnitude and Direction of Earth-Electric Components at Ebro.

11. From Table 2 it is seen that the average value for 1914-1918 of $(-N)$ was 204 (*i. e.*, current flowed from north to south), and of $(-W)$ 114 millivolts per km. (*i. e.*, current flowed from west to east). *Hence, the component of the Ebro earth currents towards true South was nearly twice (1.8 times) the component towards true East. The resultant horizontal component, R, was 234 millivolts per km., or 0.2 volt per km. The average direction (A) of the resultant was 29° east of true south, or we may say that approximately the resultant horizontal component, R, of the earth currents circulating in the Earth's crust at the Observatorio del Ebro, Tortosa, Spain, was from NNW to SSE.* It is of interest to observe in this connection that the bearing at Ebro of the Magnetic North Pole (assumed to be

approximately at 70° N, 97° W) is 24°. 5 west of true north, whereas, the bearing of the north end of the Earth's so-called magnetic axis is about 15° west of true north. Hence, *the resultant hori-*

Table 4.—*Monthly and annual values of resultant horizontal potential-gradient of earth-currents at the Ebro Observatory for the magnetically-calm days, 1914-1918, in millivolts per kilometer, and true directions of resultant horizontal component.*

Month	Resultant Horizontal Component (R)						True Direction (A), East of South					
	1914	1915	1916	1917	1918	Mean	1914	1915	1916	1917	1918	Mean*
	v/k	v/k	v/k	v/k	v/k	v/k	°	°	°	°	°	°
Jan.	585	273	126	188	46	244	26.8	29.2	35.6	30.7	52.9	29.8
Feb.	554	310	358	146	132	300	27.3	28.5	28.9	32.0	30.8	28.7
Mar.	588	350	310	264	136	330	26.7	27.4	28.0	27.4	30.7	27.6
Apr.	552	398	330	316	228	365	27.2	26.7	27.2	26.3	27.2	26.9
May.	538	315	504	324	268	390	26.4	33.0	25.7	24.5	26.5	27.0
Jun.	580	164	522	402	390	412	25.3	61.6	25.5	24.8	25.0	28.0
Jul.	611	329	348	488	447	445	26.1	24.6	25.9	24.8	24.9	25.3
Aug.	65	498	26	46	11	129	42.5	25.6	64.5	36.0	67.0	25.3
Sep.	30	33	26	20	13	24	66.6	70.3	93.4	94.8	113.0	82.6
Oct.	32	130	25	26	16	46	90.5	38.2	101.1	92.1	102.8	62.6
Nov.	27	231	25	25	52	72	78.5	31.7	105.3	98.9	42.6	45.2
Dec.	161	83	36	55	159	99	31.6	41.4	64.3	48.4	30.8	37.1
Mean	360	260	220	192	158	238	Mean *A* (1914-1918) from Table 2.					29.1

* The values in this column are not the means of those for the separate years, but were derived independently from the mean values of the rectangular components for 1914-1918.

Table 5.—*Monthly and annual values of the magnetic components at the Ebro Observatory for t magnetically-quiet days, 1914-1918.*

Month	$X = 22700\gamma$ + tab. quantity						$-Y = 4900\gamma$ + tab. quantity						$Z = 36900\gamma$ + tab. quantit					
	1914	1915	1916	1917	1918	Mean	1914	1915	1916	1917	1918	Mean	1914	1915	1916	1917	1918	Me
	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ	γ
Jan.	− 4	− 8	02	41	56	17.4	300	279	209	136	81	201.0	85	44	35	59	−26	39
Feb.	05	− 6	24	43	60	25.2	299	278	214	132	74	199.4	81	41	44	53	−25	38
Mar.	11	− 9	36	58	57	30.6	292	269	196	129	69	191.0	84	32	71	27	−30	36
Apr.	12	− 6	56	57	57	35.2	293	260	198	121	64	187.2	87	33	87	30	−23	42
May.	15	08	66	65	73	45.4	288	256	190	118	58	182.0	89	40	90	17	−17	43
Jun.	22	10	72	68	86	51.6	292	257	177	113	55	178.8	90	50	97	11	−24	44
Jul.	26	09	70	64	81	50.0	285	257	180	102	53	175.4	96	68	102	20	−15	54
Aug.	26	12	65	53	69	45.0	278	238	180	98	43	167.4	89	39	83	16	−18	41
Sep.	16	09	46	64	73	41.6	271	212	152	102	34	154.2	83	29	52	14	−23	31
Oct.	10	06	39	59	71	37.0	272	206	139	92	30	147.8	70	33	40	−39	−34	14
Nov.	− 1	− 2	42	55	65	31.8	276	211	133	88	29	147.4	61	41	38	−29	−48	12
Dec.	− 4	− 3	45	49	59	29.2	277	208	136	83	22	145.2	53	40	62	−13	−54	17
Mean	11	02	47	56	67	36.7	285	244	175	110	51	173.0	81	41	67	14	−28	34

zontal component of the earth-currents at Ebro was approximately in the direction from the Magnetic North Pole towards south-southeast.

12. Since the direction of the $N'S'$ component of the Ebro current-measurements was from 25°.3 west of north to 25°.3 east of south (see Table 1), it happens that the published values of $N'S$ do not differ very much from our computed values (Table 4) of the resultant R, the direction of which on the average, for 1914-1918, as just stated, was from 29.1° west of north to 29.1° east of south. This also explains the comparatively small magnitudes of the published values of $W'E'$.

13. Weinstein's values of the constant part of the earth currents observed at Berlin in telegraph lines from 1884-1886 (July), given on page 15 of the publication cited in footnote 2, have usually been interpreted to imply that the resultant current was on the average approximately from NE to SW. There is, however, some question as to the precise interpretation of Weinstein's signs, and it is in fact possible to interpret them so that the resultant current would flow, as at Ebro, from the NW quadrant to the SE quadrant. Anyhow, if the first interpretation as given is correct, then the resultant current for the later period, beginning August, 1886, was approximately from NNW to SSE, as at Ebro. Weinstein himself does not appear to attach much value to his tabulated quantities for the "constant" currents, but, instead, confines his discussion almost exclusively to the diurnal and annual variations of the observed earth-currents and to their relations with the magnetic variations. As at Ebro, the average constant component along the geographic meridian was, in general, larger than that along the parallel of latitude.

14. Before passing to the next topic, it may be of interest to obtain some idea of the approximate *earth-current density* at Ebro. Taking 0.2 volt per km. as the average horizontal potential-gradient of the resultant current, and making use of such data as are readily available regarding conductivity of the soil, it is found that the earth-current density at Ebro may be of the order 10^5 times that of the current density of the vertical conduction current (3×10^{-2} amperes per sq. km.) of atmospheric electricity, or about of the order of magnitude of some of the current densities obtained for the vertical electric currents resulting from line integrals of the magnetic force.[7]

15. Looking over the extreme values of the observed earth-

[7] BAUER, L. A.: On Vertical Electric Currents, etc., *Terr. Mag.*, vol. 25, p. 156.

currents at Ebro, 1910-1920, it would appear that during periods of excessive disturbance the magnitude of the horizontal potential-gradient of the resultant current may reach a value of about 0.8 volt, or more, per km.

Annual Variation of Earth Currents at Ebro.

16. From Tables 3 and 4 it will be noticed that in each year there is a remarkable change in the tabulated quantities between the summer and the fall months. Thus on the average for the 5 years we have:

Month	N	W	R	A
July	−402	−190	−445	25°.3 E of S
September	−3	−23	−24	82 .6
Change	−399	−167	−421	−57.3

Table 6 contains the preliminary data for the annual variation of the magnetic and electric components at Ebro, as derived from Tables 3, 4, and 5, approximate allowance having been made for secular change of the magnetic components and for the observed progressive change in the earth-current components during the sun-spot cycle; also, for comparison, the Berlin earth-current data are given.

17. According to the quantities at the bottom of Table 6, we find that on the average during the summer months (April to September), the magnetic component X, towards the North, is increased, i. e., dX is plus, and that the electric component W, towards the West, is decreased (or electric component towards the East is increased), i. e., dW is minus. In the winter months (October to March) the average dX is minus, whereas the average dW is plus. If the magnetic variations, dX, were the result of the electric variations, dW, then they should be of the same sign, instead of opposite sign as is the case.

Turning next to the average quantities, dY and dN, for summer and winter months, it is seen that these correspond in sign. If, however, dY were the magnetic effect of the electric variation dN, then a value of about $dN = 50$ millivolts per km. would produce a magnetic change, dY, of but 1γ. Since the variations, dW, are in general considerably smaller than the dN, it is, accordingly, perhaps not surprising that no corresponding effect is readily discernible in the dX.

TABLE 6.—*Preliminary mean values of the annual variations of the magnetic components and of the earth currents at the Ebro Observatory for the magnetically-quiet days, 1914–1918.*

(Mean values for 1914–1918: Magnetic components, $X = 22736.7\gamma$, $Y = -5073.0\gamma$, $Z = 36934.8\gamma$; earth-current components, in millivolts per kilometer, $N = -204.4$, $W = -113.8$. Meaning of signs: +, numerical increase of X and Z, and algebraic increase of Y, N, W, and R. For the sake of comparison, the last column has been added, giving the annual variation of the resultant current in arbitrary units, a, at Berlin, as based on the Weinstein data for 1884–1887.)

Month	Mag. Comp.	Elec. Comp.	Mag. Comp.	Elec. Comp.	Mag. Comp.	Res. El. Comp. Ebro	Res. El. Comp. Berlin
	dX	dW	dY	dN	dZ	dR	dR
	γ	v/k	γ	v/k	γ	v/k	a
Jan.	−11.6	+4	−0.3	+13	−6.6	−6	+101
Feb.	−5.1	−22	−3.8	−43	−5.1	−62	+42
Mar.	−1.1	−32	−0.4	−76	−5.1	−92	−40
Apr.	+2.1	−47	−1.6	−112	+2.9	−127	−75
May	+10.9	−60	−1.5	−137	+6.0	−152	−60
Jun.	**+15.7**	−75	−3.3	−152	+9.0	−174	−61
Jul.	+12.7	*−77*	*−4.9*	*−199*	**+20.4**	*−207*	*−84*
Aug.	+6.3	+47	−1.9	+89	+10.0	+109	−47
Sep.	+1.5	**+86**	+6.2	**+193**	+1.3	**+214**	−5
Oct.	−4.5	+72	**+7.6**	+174	*−13.7*	+192	+18
Nov.	−11.1	+59	+3.0	+143	−13.1	+166	+88
Dec.	*−15.0*	+45	+0.1	+108	−6.0	+139	**+121**
Mean (Apr.-Sep.)	+8.2	−21	−1.2	−53	+8.3	−56	−55
Mean (Oct.-Mar.)	−8.1	+21	+1.0	+52	−8.3	+56	+55
Range	30.7	163	12.5	392	34.1	421	205

The signs given the annual variation, dR, of the resultant horizontal potential-gradient of the earth current, both at Ebro and Berlin, have the following significance: A plus value means a decrease and a minus sign an increase in the current flowing towards the Southern Hemisphere. It is seen from Table 6 that for both stations the potential gradient of the current flowing towards the Southern Hemisphere, on the average, is increased in the summer and decreased in the winter months.

18. The Fourier analysis (Table 7) of the annual variations given in Table 6 likewise shows that excepting as to the fourth term, there is practically no correspondence between dX and dW. On the other hand, the correspondence in phase for the principal terms (first two) between dY and dN is fairly good, though the ratio of the respective amplitudes c_1/c_2 differ as 1.1 to 2.9. If the dW and dN were the result of variations in the Earth's magnetism, then they should show some decided relationship to the derivatives $d(dX)/d\theta$ and $d(dY)/d\theta$, respectively, but evidently this is not the

case. *We must accordingly conclude that the annual variations, observed at the Ebro Observatory, of the potential gradients of the earth currents and of the components of the Earth's magnetism, may be related to one another as cause and effect only to a very minor extent: both sets of variations may have to be referred, more or less, to common causes.*

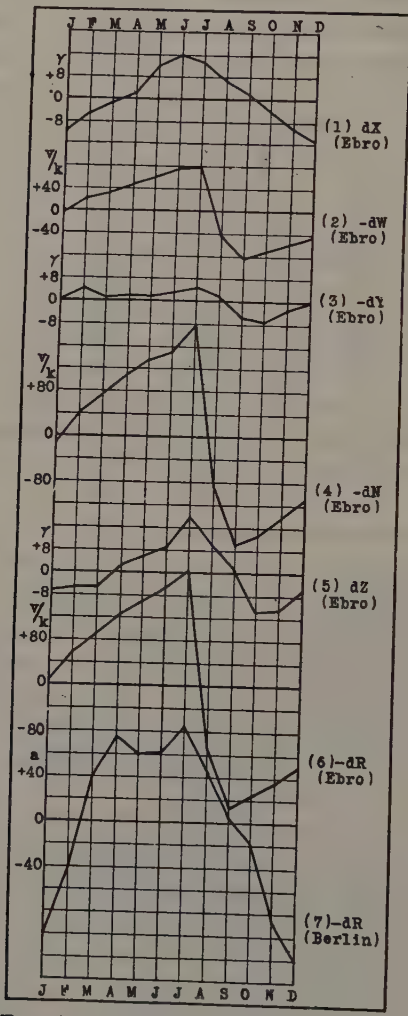

FIG. 1—Annual Variation of Earth-Current Potential-Gradients and of Magnetic Components.

19. Fig. 1 is a graphical representation of the data in Table 6. The chief facts shown by the various curves have already been stated in the preceding paragraphs. It should be noted that Curves 2, 3, 4, 6, and 7 have been plotted inverted. The annual variation, *dR*, of Weinstein's resultant current at Berlin, given in the last column of Table 6, follows a somewhat similar course to the annual variation *dR*, of the resultant current at Ebro (see curves 6 and 7), though there are some discordances, to be referred possibly to local or disturbing causes. From Curves 2, 4, and 6, it is seen that the annual variation in the Ebro currents, as already pointed out in paragraph 16, is most marked between July and September; it would be of interest to know whether there are any local contributing causes, such as meteorological ones, for example.

TABLE 7.—*Fourier analysis of annual variation of magnetic and electric components at the Ebro Observatory for the magnetically-calm days, 1914–1918.*

[Annual variation, dX, dW, etc. $= c_1 \sin(\theta + \phi_1) + c_2 \sin(2\theta + \phi_2) \ldots$; θ is counted from midnight of Dec. 31, at rate of 30° per average month.]

Quantity	Mag. Comp.	Elec. Comp.	Mag. Comp.	Elec. Comp.	Mag. Comp.	Res. El. Comp.	
						Ebro	Berlin
	dX	dW	dY	dN	dZ	dR	dR
	γ	v/k	γ	v/k	γ	v/k	v/k
c_1	13.4	72.8	3.7	169	11.9	192	94
c_2	0.4	26.6	3.2	59	5.7	63	27
c_3	2.1	17.8	1.3	38	2.8	42	12
c_4	0.4	12.1	1.0	31	0.8	37	10
c_1/c_2	36.1	2.7	1.1	2.9	2.1	3.0	3.5
	°	°	°	°	°	°	°
ϕ_1	279	148	152	146	278	148	107
ϕ_2	48	277	245	269	52	266	107
ϕ_3	317	87	15	73	140	86	45
ϕ_4	208	210	105	204	45	204	217

Diurnal Variation of the Magnetic and Electric Components.

20. Table 8 contains the diurnal-variation data for the magnetic components (X, Y, Z) and for the electric quantities (N, W, R, A), as derived from the Ebro magnetic observations and earth-current measurements with the aid of the formulæ given in paragraph 9, all for the magnetically-calm days (5 per month), 1914–1918. The data were obtained for the 4 winter months (Group I), November–February; (Group II), for the spring and autumn months, March, April, September, and October; and

Table 8.—*Mean diurnal variations for the year of the magnetic and electric components at the Ebr Observatory for the magnetically-calm days, 1914–1918.*

[Meaning of signs: +, numerical increase of X and Z, and algebraic increase of Y, W, N, and I since the values of the latter quantities, according to paragraph 10 and Tables 2, 3, and 4, are a negative. A − sign of $\triangle A$ means a change in azimuth of resultant, R, from South towards Eas

G.M.T.	Mag.	El.	Mag.	El.	Mag.	El. Resul.		G.M.T.	Mag.	El.	Mag.	El.	Mag.	El. Resul	
	$\triangle X$	$\triangle W$	$\triangle Y$	$\triangle N$	$\triangle Z$	$\triangle R$	$\triangle A$		$\triangle X$	$\triangle W$	$\triangle Y$	$\triangle N$	$\triangle Z$	$\triangle R$	$\triangle$
h	γ	v/k	γ	v/k	γ	v/k	′	h	γ	v/k	γ	v/k	γ	v/k	′
1	+0.2	−1.0	+4.3	−1.8	+3.9	−2	−2	13	−2.3	−2.4	−28.6	−7.4	−13.3	−7	−2
2	+0.3	−0.7	+4.2	−1.1	+3.9	−1	0	14	−3.3	+0.9	−26.1	+1.5	−8.2	+2	−
3	+0.3	−0.4	+4.2	−0.3	+3.9	−1	+3	15	−3.9	+3.6	−18.5	+8.3	−2.3	+9	+1
4	+1.4	+0.8	+5.2	+2.4	+4.4	+3	+7	16	−3.0	+5.1	−9.9	+12.1	+2.2	+13	+2
5	+2.4	+1.7	+7.9	+4.5	+5.1	+5	+11	17	−1.1	+5.0	−4.0	+11.7	+4.6	+13	+2
6	+2.8	+1.7	+12.1	+4.7	+5.3	+5	+13	18	+1.4	+4.4	−1.0	+10.3	+5.2	+11	+2
7	+1.7	+1.3	+17.0	+3.9	+4.8	+4	+11	19	+3.4	+2.7	−0.1	+6.4	+4.7	+7	+1
8	−1.1	+0.4	+21.8	+1.5	+2.8	+1	+5	20	+4.5	+1.4	+1.0	+3.9	+4.3	+4	+1
9	−4.9	−3.4	+20.6	−8.0	−3.0	−9	−8	21	+4.6	+0.1	+1.7	+1.0	+3.8	+1	+
10	−6.9	−6.5	+9.1	−16.6	−10.3	−18	−37	22	+4.7	−0.6	+2.5	−0.7	+3.3	−2	+
11	−5.8	−6.8	−8.0	−18.2	−15.1	−19	−44	23	+4.4	−1.2	+3.1	−1.9	+3.0	−2	+
12	−3.5	−5.1	−22.2	−14.2	−16.0	−15	−38	24	+3.9	−1.2	+3.6	−2.1	+2.8	−2	

Table 8*a*.—*Values of* $\Delta Y'$ *and of* ΔD *for the Ebro Observatory. 1914–1918.*

[+ means motion of north end of magnetic needle towards East.]

G.M.T.	ΔY′	ΔD	G.M.T.	ΔY′	ΔD	G.M.T.	ΔY′	ΔD	G.M.T.	ΔY′	ΔD	G.M.T.	ΔY′	ΔD	G.M.T.	ΔY′	ΔD
h	γ	′	h	γ	′	h	γ	′	h	γ	′	h	γ	′	h	γ	′
1	+0.7	+0.6	5	+3.2	+1.2	9	−6.9	+2.8	13	−2.2	−4.2	17	+4.1	−0.6	21	+1.2	+0.4
2	+0.5	+0.6	6	+5.9	+1.8	10	−14.4	+1.1	14	+6.0	−3.9	18	+1.4	−0.1	22	+0.6	+0.5
3	+0.2	+0.6	7	+6.0	+2.5	11	−16.5	−1.3	15	+9.3	−2.8	19	+0.8	+0.1	23	+0.2	+0.6
4	+0.9	+0.8	8	+1.4	+3.1	12	−11.4	−3.3	16	+7.7	−1.5	20	+1.1	+0.3	24	+0.3	+0.6

(Group III), for the 4 summer months, May–August. Finally, the data for the whole year, and for the entire period 1914–1918, were obtained and these alone are given in Table 8. The significance of the signs, as stated at the top of the table, is in accordance with paragraph 10. The geographic position of the Ebro Observatory is 40° 49′ N, and 0° 31′ E. Accordingly, G. M. T. hours are within two minutes of the local hours.

Table 9 contains the results of the Fourier analysis of the diurnal variations of the magnetic and electric data given in Table 8, as also of the potential gradient, P, of atmospheric electricity at Ebro for the mean of the years, 1914–1918. For the purpose of comparison, the last two columns are added, based upon Weinstein's Berlin data (1884–1887) as given by Chree[8]; the quantities

[8] *Encycl. Brit.*, 11th ed., vol. 8, p. 815.

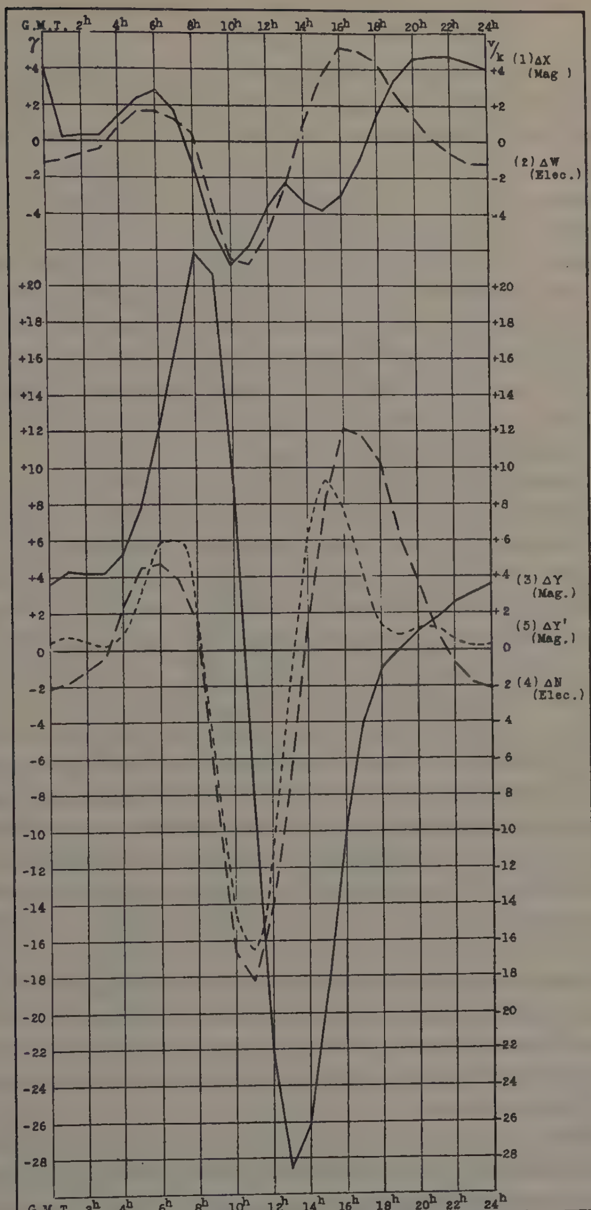

FIG. 2.—Diurnal Variation of Horizontal Magnetic Components and of Earth-Current Components.

apply to the astronomical directions and are expressed in arbitrary units, *a*.

21. Fig. 2 shows the curves based on the data in Table 8. It is seen that while there is some general agreement in Curves 1 and 2 ($\triangle X$ and $\triangle W$), they cannot be related as effect and cause, respectively, as would be the case, if $\triangle X$ were simply the magnetic effect of $\triangle W$. Not only is the principal minimum of the two curves displaced about an hour with reference to one another, that for the electric curve occurring later, but the curves show a marked discordance for the portion of the day between 14^h (2 P. M.) and midnight. The same general facts are disclosed by the curves, not given here, which were drawn for the separate Groups I, II, and III. Both the magnetic and the electric curves show a greater development during the summer months (Group III) than for the winter months (Group I).

22. Passing next to Curves 3 and 4, $\triangle Y$ and $\triangle N$, each shows a much greater development than was the case for the previous curves. While again there is some similarity between $\triangle Y$ and $\triangle N$, the principal maxima and minima of the $\triangle N$-curve occur about two hours earlier than those for the $\triangle Y$-curve. Thus again no direct relationship is indicated between the electric variation ($\triangle N$) and the magnetic variation ($\triangle Y$), as cause and effect, respectively. If now we compare the $\triangle Y'$-curve (No. 5) showing the rate of change per hour in the west-east magnetic component, a striking similarity is found between $\triangle Y'$ and $\triangle N$. Curve 5 was drawn by aid of computed quantities derived from the Fourier coefficients (see Tables 8*a* and 9). The principal minimum of Curves 4 and 5 occurs at the same time; the principal maxima of the two curves are displaced with reference to one another about one hour, first in one direction, then in the opposite direction. *The general conclusion is that the north-south earth-current might be the result of electro-magnetic induction, caused by the fluctuation during the day of the west-east component of the Earth's magnetism.*[9]

As in the case of Curves 1 and 2, the development of Curves 3, 4, and 5, is greater for the summer (Group III) than for the winter months (Group I).

23. Fig. 3 shows the diurnal-variation curves, $\triangle Z$ and $\triangle R$. A general similarity between the magnetic and the electric curves is again evident; however, the displacement of the principal maxima and minima is about two hours, those of the electric curve (2)

[9] *Cf.* Steiner, L.: On Earth-Currents and Magnetic Variations; *Terr. Mag.*, vol. 13, 1908, pp. 58-62.

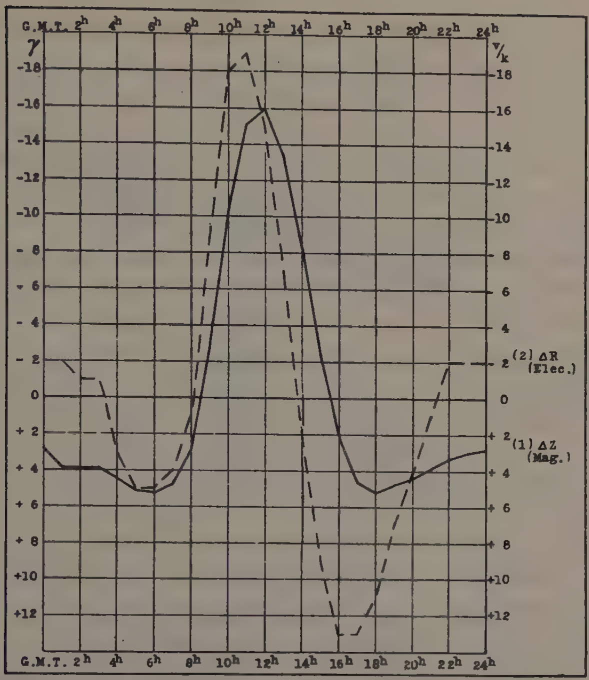

FIG. 3.—Diurnal Variation of Vertical Magnetic Component and of Resultant Earth-Current Potential-Gradient.

occurring earlier than those of the magnetic curve 1. Thus, an immediate relationship between the diurnal variation of the resultant horizontal potential-gradient of the earth-current and the diurnal variation of the vertical component of the Earth's magnetism, as cause and effect, is not disclosed. The development of both ΔZ and ΔR is greater in summer (Group III) than in winter (Group I).

24. Figs. 4-7 show the horizontal-vector diagrams for the years 1914 (one year after year of minimum sun-spot activity) and 1917 (the year of maximum sun-spot activity). Figures 4 and 7 represent the ΔX and ΔY magnetic variations, whereas 5 and 6 show the ΔN and ΔW electric variations. Both pairs of curves show the largest development during the year of maximum sun-spot activity, the relative enlargement of diagram-area for 1917 over that for 1914 being approximately the same for the magnetic and the electric curves.

There is a striking difference between the magnetic diagrams

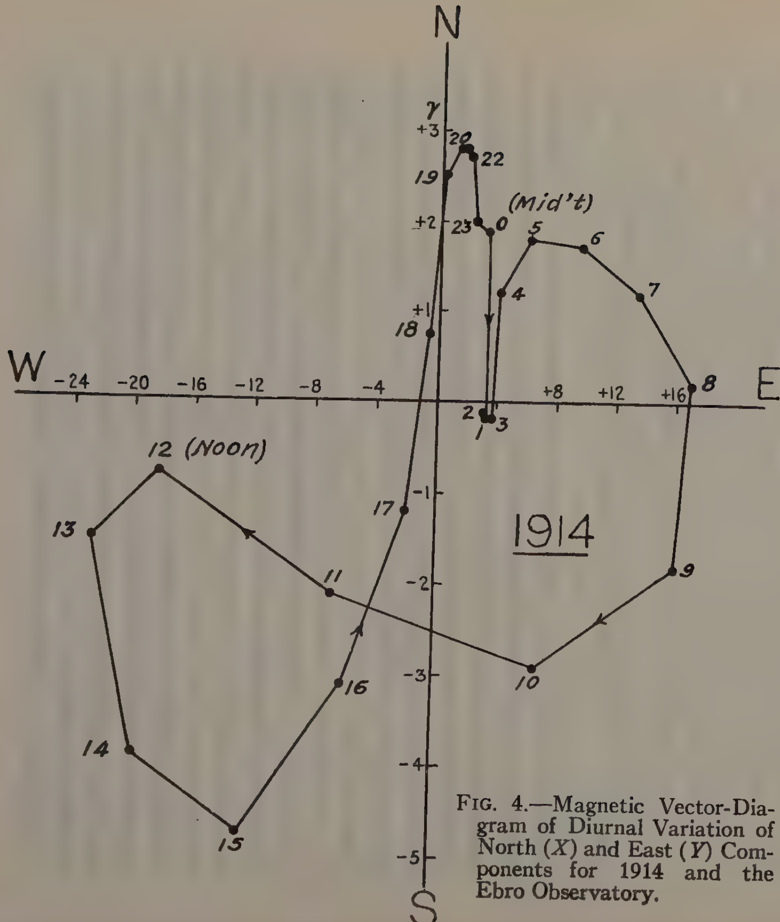

FIG. 4.—Magnetic Vector-Diagram of Diurnal Variation of North (*X*) and East (*Y*) Components for 1914 and the Ebro Observatory.

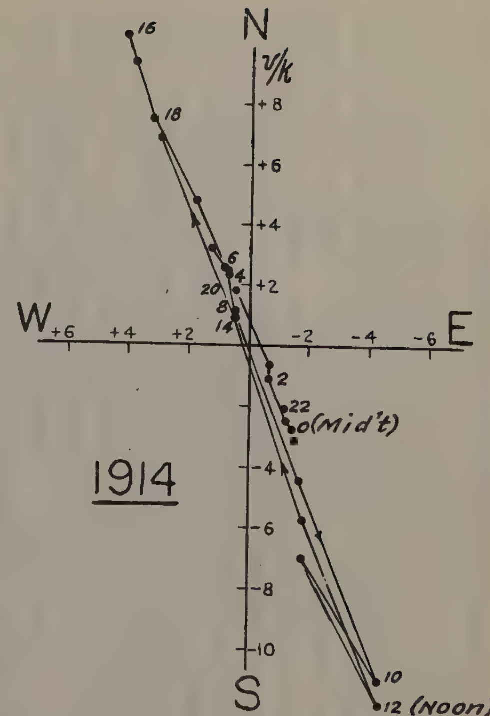

FIG. 5.—Earth-Current Vector-Diagram of Diurnal Variation of North (*N*) and West (*W*) Components for 1914 and the Ebro Observatory.

(Figs. 4 and 6) and the electric diagrams (Figs. 5 and 7). While the former are somewhat symmetrical about the true meridian (NS-line), the latter are symmetrical about a line running, on the average, from about 24° E of S to about 24° W of N, which is approximately the direction towards the Magnetic North Pole (see paragraph 11). The development of the electric diagrams at right angles to this direction, as is seen, is very limited. It will be seen that the general direction in which both the magnetic and the electric vector-diagrams are described is for the greater part the same as that of the hands of a clock.

Fig. 8 exhibiting the diurnal changes in the magnetic declination and in the direction of the resultant horizontal earth-current once more emphasizes some of the difficulties of associating the earth-current and the magnetic phenomena as cause and effect. It will be seen that the character of the electric curve is considerably different from that of the magnetic curve; for the former the amplitude of the 12-hour wave is larger than that of the 24-hour one, whereas for the latter, just the reverse is the case.

25. Fig. 9 shows that there is as good an agreement between the results of the earth-current measurements at Ebro and Berlin, as could be expected, especially if the difference in method of measurement and local conditions be taken into account.

26. The Fourier analyses of the diurnal variations, as given in Table 9, once more confirm the chief facts set forth in the preceding paragraphs. There is no general agreement in the phase angles and relative amplitudes for $\triangle X$ and $\triangle W$, nor for $\triangle Y$ and $\triangle N$, nor for $\triangle Z$ and $\triangle R$. There is, however, a better agreement in the phase-angles and relative amplitudes for the $\triangle Y'$ (time derivative of $\triangle Y$) and $\triangle N$; but the agreements are not sufficiently close to enable one to draw a final conclusion as to the precise relation between $\triangle Y'$ and $\triangle N$.

27. Comparing the colums $\triangle W$ and $\triangle N$ for Ebro with the corresponding ones for Berlin, a general agreement is evident. The phase-angles are practically in agreement for local mean time at each station; if they are referred to the same time (G. M. T.) the agreement in some of the phase-angles is somewhat improved, as though a portion of the diurnal variation of earth currents may progress according to universal time, rather than local time. It is unfortunate for the settlement of this extremely interesting question that sufficiently extensive earth-current data for a station

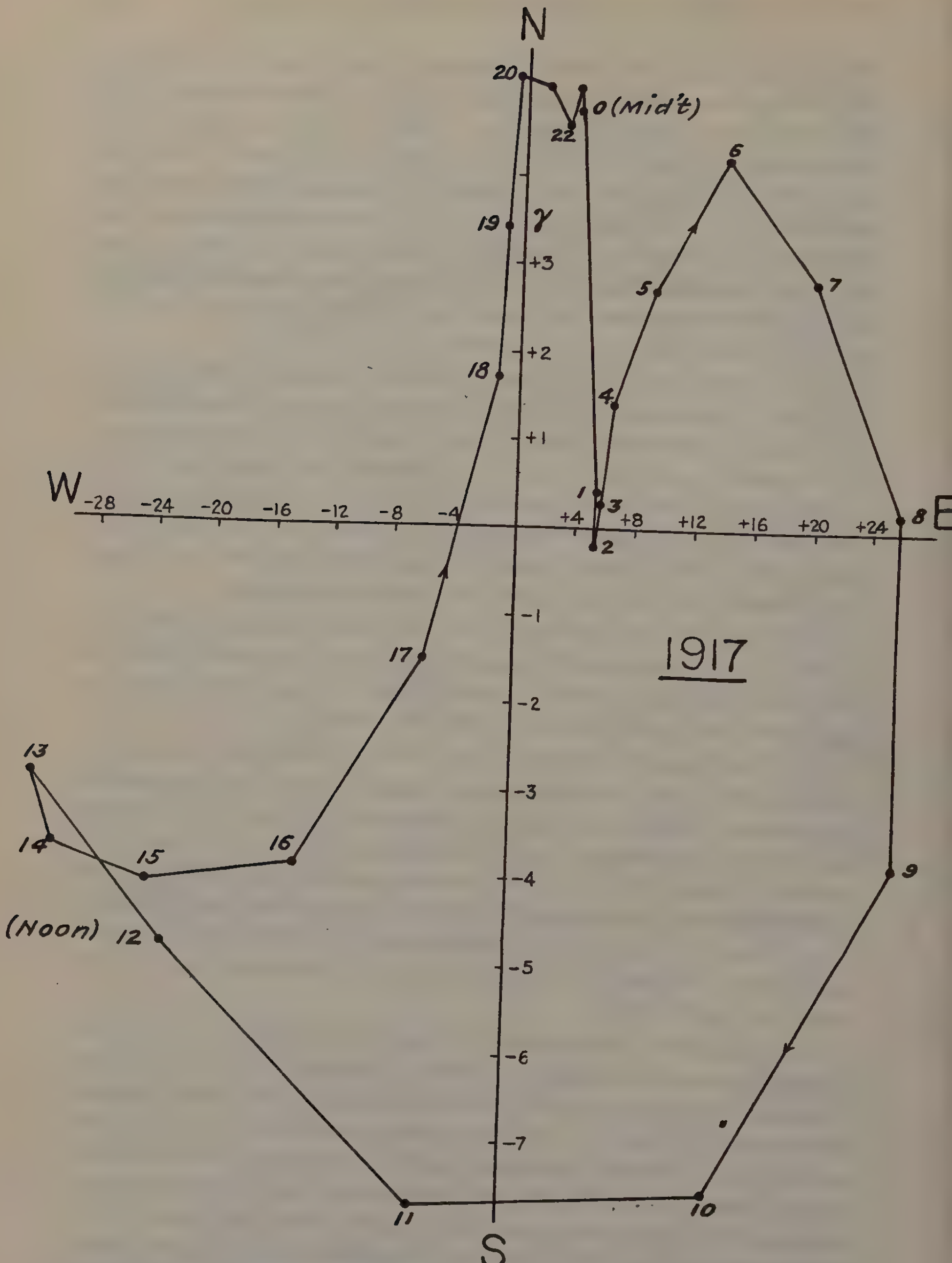

FIG. 6.—Magnetic Vector-Diagram of Diurnal Variation of North (X) and East (Y) Components for 1917 and the Ebro Observatory.

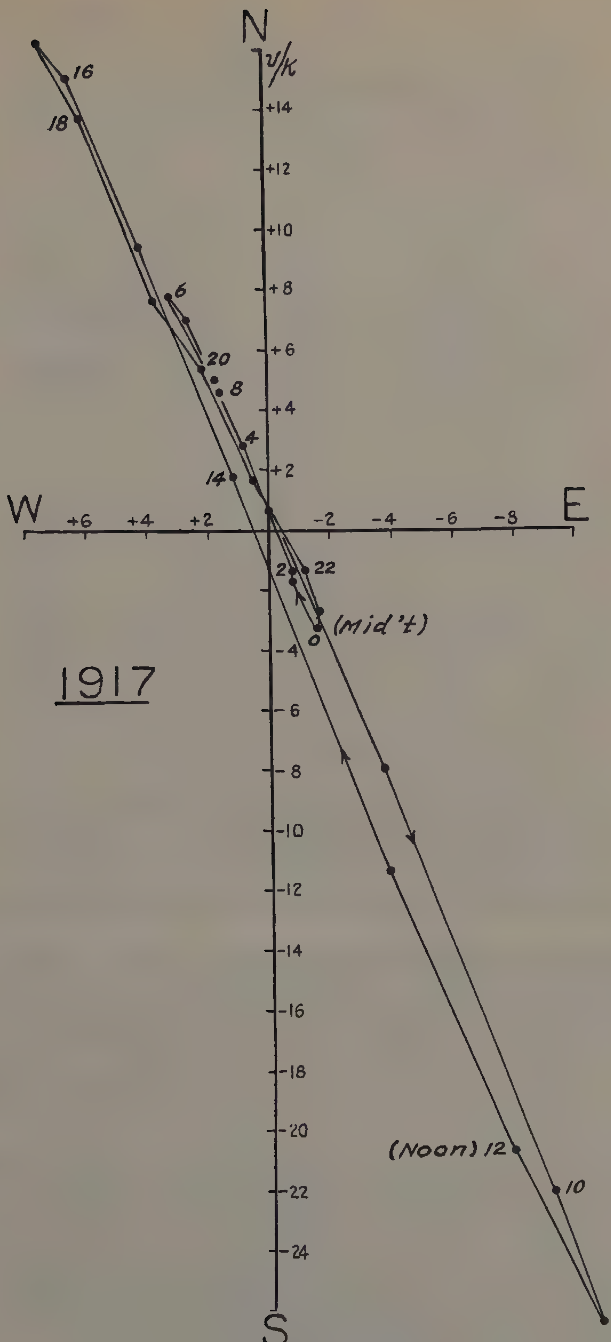

FIG. 7.—Earth-Current Vector-Diagram of Diurnal Variation of North (N) and West (W) Components for 1917 and the Ebro Observatory.

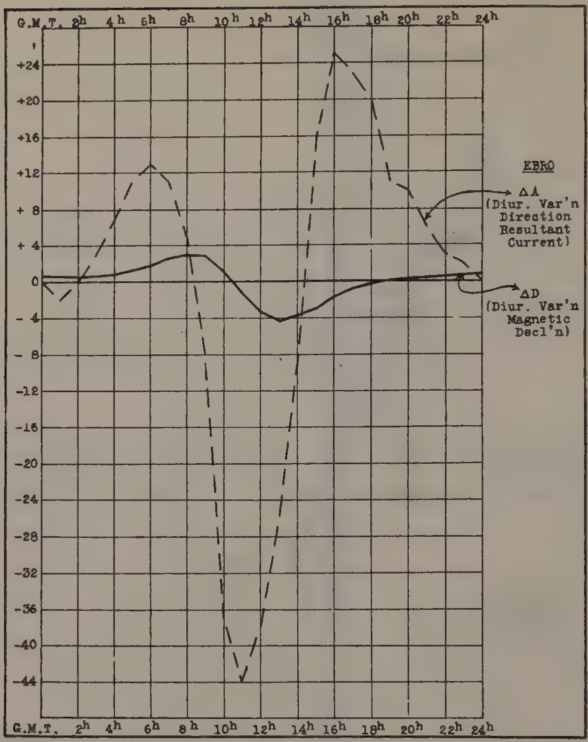

Fig. 8.—Diurnal Variation of Magnetic Declination and of Direction of Resultant Earth-Current for 1914-1918 and the Ebro Observatory.

differing more widely in longitude from Ebro, than Berlin, are not available.

28. It is also of interest to compare the results of the Fourier analysis of the atmospheric-electric potential-gradient, $\triangle P$, at Ebro, given in Table 9, with those for the earth-current diurnal variation ($\triangle W$, $\triangle N$, $\triangle R$) at the same station. There is no agreement in phase-angles except approximately for the fourth term.

29. *The average diurnal-variation quantity, or average departure* (A. D.) of any element from its mean value for the day, regardless of sign, was computed for each month of the 5 years, 1914–1918. The mean values of these quantities are given in Table 10 for the magnetic components X, Y, and Z, first according to season, and next for each year. The figures in column "Win.", are for the 4 months (Nov.–Feb., Group I); those in column "S A" are for

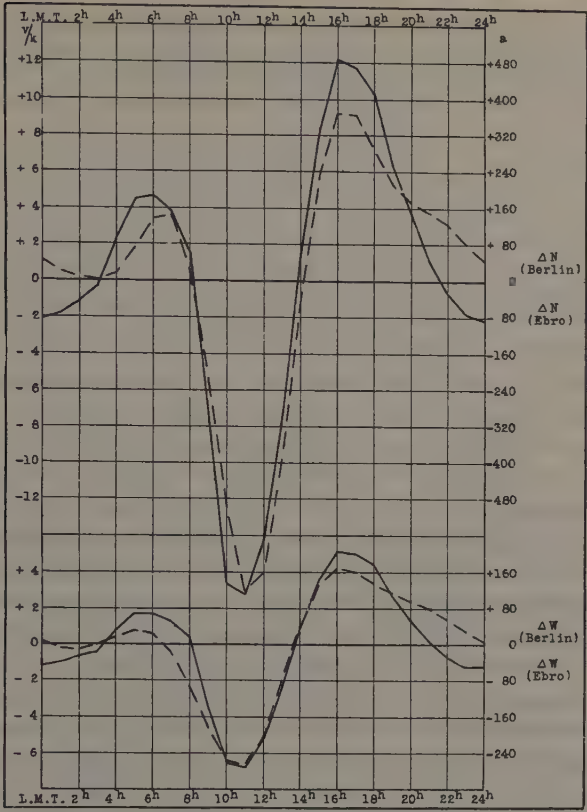

FIG. 9.—Diurnal Variation of Earth-Current Components for the Ebro Observatory, 1914-1918, and for Berlin (Weinstein data, 1884-1887).

TABLE 9.—*Fourier analysis of the diurnal variation of the magnetic and electric components at Ebro Observatory for the magnetically-calm days, 1914–1918.*

Quantity	Magnetic (Ebro)				Electric (Ebro)				Elec. (Berlin)	
	ΔX	ΔY	ΔZ	$\Delta Y'$	ΔW	ΔN	ΔR	ΔP	ΔW	ΔN
	γ	γ	γ	γ	v/k	v/k	v/k	V/m	*a*	*a*
c_1	4.13	12.76	7.19	12.76	2.09	5.34	4.79	19.42	122.9	241.7
c_2	1.58	11.41	5.96	22.82	3.63	9.02	8.95	15.76	106.7	265.0
c_3	1.76	6.65	2.55	19.95	1.41	3.84	3.64	2.81	50.8	163.6
c_4	1.10	2.17	0.74	8.68	0.38	1.07	0.94	6.77	10.9	49.3
c_1/c_2	2.62	1.12	1.21	0.56	0.58	0.59	0.53	1.23	1.2	0.9
	°	°	°	°	°	°	°	°	°	°
ϕ_1	99.0	34.8	90.0	124.8	151.3	141.2	146.3	209.6	143.0	126.5
ϕ_2	236.4	219.5	273.4	309.5	297.4	295.5	296.5	196.4	303.5	286.3
ϕ_3	199.4	52.9	95.8	142.9	125.5	124.4	125.1	284.6	147.8	114.8
ϕ_4	61.4	245.5	303.0	335.5	350.7	335.4	342.8	331.0	315.8	295.6

Variations During the Year and the Sun-spot Cycle.

TABLE 10.—*Average departure of diurnal-variation quantities at the Ebro Observatory for the magnetically-calm days, 1914–1918.*

Quantity		For Season			For Year				
		Win.	S. A.	Sum.	1914	1915	1916	1917	1918
		γ	γ	γ	γ	γ	γ	γ	γ
Mag. Component.......	X	4.1	4.2	4.5	3.6	3.8	5.1	4.9	3.9
	Y	6.5	12.0	13.2	7.9	9.6	10.9	11.9	10.6
	Z	3.1	6.8	7.5	4.5	4.8	6.4	6.8	6.5
		v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k
Elec. Resultant	R	6.9	8.8	9.7	6.0	8.0	8.4	10.2	9.6

the 2 Spring months and 2 Autumn months (Mar., Apr., Sep., Oct., Group II); and those in column "Sum." are for the 4 months (May–Aug., Group III). For the diurnal variation of the earth-current potential-gradients, the average departures were deduced from the published potential-gradient along the N′S′ line (see paragraph 7); the quantities so obtained may be regarded as practically the same as what they would be for the resultant horizontal potential-gradient, R, for the reason stated in paragraph 12.

It will be seen that the average-departure quantities, for both terrestrial magnetism and earth currents, are largest for the summer and vary during the sun-spot cycle, increasing, in general, with increased sun-spot activity, maximum sun-spot activity having occurred in 1917.

30. Table 11 was drawn up with the aid of the published values of the extreme diurnal range (difference between recorded maximum and minimum potential-gradients during the day) of the earth-current measurements along the N′S′ line (paragraph 7) for each day and for the entire period, 1910–1920. The mean monthly and annual values of these ranges are given, I, taking all days into consideration, and II, taking only the comparatively undisturbed days, namely, those designated as of electric character 0 and 1. According to paragraph 12 we may regard the ranges for the component N′S′ as approximations, sufficient for our purposes, to the ranges for the resultant horizontal potential-gradient, *R*.

It will be seen that the extreme diurnal range of the Ebro earth-current potential-gradients reaches its highest values near the equinoctial months, and that it varies during the sun-spot cycle, the minimum value occurring near the year (1913) of sun-spot minimum and the maximum near the year (1917) of sun-spot maximum.

TABLE 11.—*Variation in extreme diurnal range of resultant horizontal potential-gradient of earth currents at the Ebro Observatory, 1910–1920, in millivolts per kilometer.*

For	Variation in Range During the Year, 1910–1920.											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k	v/k
I. All Days...	*84*	*84*	**103**	96	*87*	90	90	100	100	**113**	96	87
II. Days (0, 1).	*60*	67	74	**75**	*67*	68	76	78	73	**83**	67	*60*
	Variation in Range During the Sun-spot Cycle.											
	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	Mean
I. All Days...	70	85	68	*61*	73	94	114	113	113	**130**	114	94
II. Days (0, 1).	69	62	*57*	58	62	72	85	**89**	83	84	58	71

31. The maximum range for Series I (All Days) occurred in 1919, or two years subsequent to the year of sun-spot maximum, whereas for the undisturbed days alone (Series II), the maximum range occurred in the same year as the sun-spot maximum. *Series I shows the effect of disturbances, as the result of which earth currents are generated that die out but gradually and cause a lag in the maximum. There is a similar lag in polar-light frequencies at the time of maximum sun-spot activity.*

32. In order to study more closely the annual variation in the

TABLE 12.—*Annual variation of diurnal range of earth-currents and of atmospheric-electric potential-gradients at Ebro, 1910–1920, compared with annual variation of Aurora-Borealis frequency and of terrestrial magnetic disturbances.*

Month	Ebro E. C. (R) Days 0, 1	Ebro E. C. (R) Days All	Ebro A. E. Days 0, 1	Aur. Bor. 58°–51°	M. C. 1910 to 1920
	v/k	v/k	V/m		
Jan.......	*60*	*84*	*111*	9.4	0.61
Feb.......	67	84	125	11.8	0.65
Mar......	74	**103**	**129**	**12.2**	**0.70**
Apr.......	**75**	96	109	10.0	0.62
May......	*67*	*87*	96	2.8	0.62
Jun.......	68	90	90	*0.4*	*0.53*
Jul.......	76	90	*87*	1.2	0.55
Aug......	78	100	91	5.3	0.65
Sep.......	73	100	108	13.6	0.67
Oct.......	**83**	**113**	**139**	**15.0**	**0.72**
Nov......	67	96	129	10.9	0.61
Dec.......	*60*	87	126	*8.2*	*0.60*
Mean.....	71	94	112	8.4	0.63
Curve.....	(1)	(3)	(2)	(4)	(5)

range of the earth-current potential-gradients and to see how it may be related to other geophysical phenomena, Table 12 was prepared for the construction of Fig. 10. The data in column 4 are according to Ellis[10] for the region 58° N—51° N, and those in column 5 are the mean magnetic character numbers for the 11-year cycle, 1910–1920, which may serve as measures of terrestrial magnetic disturbances in the course of the year. It will be seen from an inspection of Fig. 10 that all curves show maxima near the

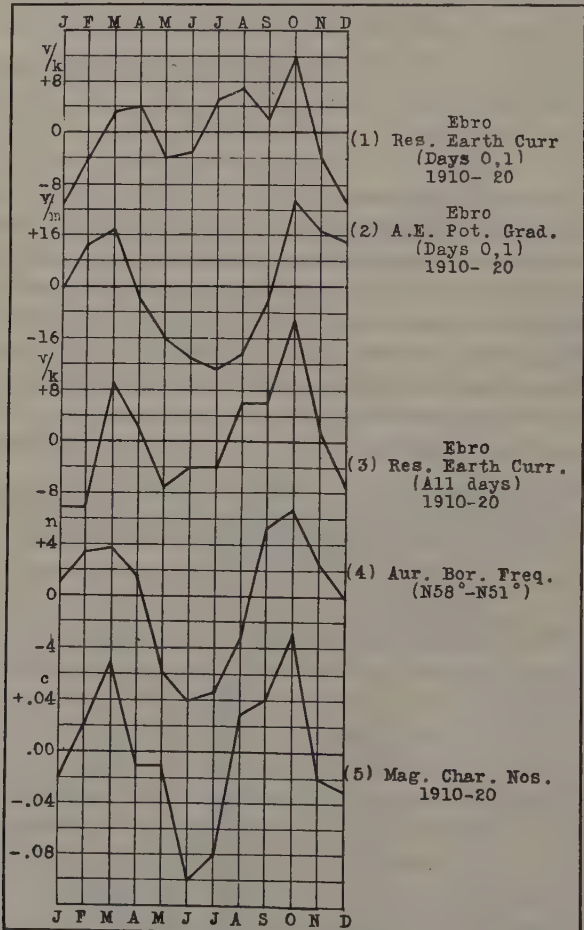

FIG. 10—Annual Variation of Diurnal Range of Electric and Magnetic Phenomena.

[10] *Mon. Not. R. A. S.*, 1904, p. 229.

equinoctial months and minima near the solstitial months, and what is of especial interest, *the principal maximum for each curve occurs in October, thus exhibiting a lag of about a month with respect to the autumn equinox. Thus earth currents, atmospheric electricity, the Aurora Borealis and the Earth's magnetic disturbances, all show closely similar annual variations in the ranges of their fluctuations.*

33. It will be of interest here to recall that Tromholt[11], who investigated disturbances in telegraph lines at four stations in Norway during three years, 1881–1884, found "that the periods of the telegraphic disturbances are identical with those of the Aurora Borealis, i. e., that their minima occur at the solstices, and their maxima at the equinoxes".

Annual Changes During the Sun-spot Cycle.

34. Table 13 shows how the potential-gradients of earth currents and of atmospheric electricity change from year to year during the 11-year sun-spot cycle, 1910–1920, for the electrically-undisturbed days (character 0 and 1). In the first two rows are the available earth-current data as obtained from the Ebro bulletins; these apply to the directions of measurement, $N'S'$ and $W'E'$ (see paragraph 7). The directions and signs have been reversed in our table in order to conform to the conventions adopted in paragraph 10. The values of α (angle between $N'S'$ and R, resultant), R, A, N, and W, were then computed with the aid of Father Ubach's formulæ and those given in paragraph 9. For the years where values of W were lacking, it was necessary to adopt mean values of α (3°.9) and of A (29°.2) obtained from the years of complete measurements, 1913–1918. The quantities thus derived are shown in parentheses; they are probably correct within 2 units for the reason stated in paragraph 12. For 1910, owing to various reasons, all the results may be so uncertain, as to necessitate their being left out of consideration here. A sign was also given to R in order to indicate that the resultant current flows towards the Southern Hemisphere.

The annual values of the potential-gradient of atmospheric electricity are complete for the entire period. The bottom rows contain the Wolfer sun-spot numbers and the D-measure (average departures of daily sun-spot numbers from monthly mean)[12] for 1910–1920.

[11] *Tromholt, S.*, Under the rays of the Aurora Borealis, vol. 1, 1885, pp. 276-282.

[12] BAUER, L. A., *Terr. Mag.*, vol. 26, 1921, p. 47.

TABLE 13.—*Annual changes during sun-spot cycle, 1910–1920, of earth-current potential-gradients, in millivolts per kilometer, and of atmospheric-electric potential-gradients, in volts per meter, at the Ebro Observatory, for the electrically undisturbed days.*

Quantity	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	Remarks
S′N′ = N′	−136	.....	*−448*	−297	−357	−255	−213	−187	**−155**	−289	−370	Earth Current
E′W′ = W′	....	.....	....	−26	−20	−25	−18	−13	**−12**	....	....	
S N = N	(−119)	.....	*(−392)*	−259	−316	−221	−186	−164	**−135**	(−252)	(−323)	
E W = W	(−66)	.....	*(−219)*	−148	−167	−130	−106	−90	**−75**	(−141)	(−181)	
R	(−136)	.....	*(−449)*	−298	−357	−256	−214	−187	**−155**	(−290)	(−371)	
α	....	.....	....	4.5°	2.6°	5.1°	4.3°	3.4°	3.8°	....	....	
A (E of S)	....	.....	....	29.7	27.9	30.4	29.6	28.7	29.0	....	....	
Pot. G. . .	113	116	113	110	*109*	111	121	**130**	126	110	109	At. Elec
S. N.	18.6	5.7	3.6	*1.4*	9.6	47.4	57.1	**98.8**	77.6	63.1	38.7	Solar Activity
S. D.	10.7	5.5	3.9	*2.1*	7.2	21.2	24.7	**29.6**	26.0	21.9	17.2	

35. It will be seen from the table that the earth-electric components tend to decrease numerically, or increase algebraically, with increased sun-spot activity, i. e., *the potential-gradients in the direction of the normal flow of the earth currents at Ebro, namely, towards south and east, decrease as sun-spot activity increases. The lowest numerical values are reached in 1918, or a year subsequent to that of sun-spot maximum. Once more, accordingly, there is evidence of a lag in earth currents with increased solar activity* (see also paragraph 31). The conclusion apparently resulting was expressed as follows in my 1921 paper[13]:

"The Earth's magnetic energy and average intensity of magnetization, as well as the strength of the normal electric currents circulating in the Earth's crust, suffer a diminution during increased solar activity. The electric currents induced in the Earth during periods of increased solar activity are in general reversed in direction to the normal currents, the strength of these superposed currents increasing with increased solar activity."

36. It may be pointed out that the two phenomena stated in this conclusion—diminished intensity of magnetization of the Earth and diminished strength of the normal earth-electric currents—are not in harmony with each other and, in consequence, cannot be related as cause and effect. The diminished intensity of magnetization is caused chiefly by diminution in the north magnetic component, X, and this, in accordance with paragraph 10, would imply a diminished electric current towards the West, instead of towards the

[13] *Terr. Mag.*, vol. 26, 1921, p. 67.

East, as shown by the quantities in Table 13. If we may place full reliance on the earth-electric quantities, it is seen again, as in paragraphs 18, 21, and 22, that *a causal relationship between certain phenomena of terrestrial magnetism and earth currents cannot be immediately concluded to exist, except in a minor degree. It would seem rather that the variations of both the magnetic and the electric phenomena are the effects of a common cause.*

37. It is extremely unfortunate for further investigation of these important indications, that no other series of earth-current observations as extensive as those at Ebro, are available. Could reliance be placed on values given by Weinstein (see paragraph 13) for the "constant" currents measured at Berlin, 1884–1887, we would have to conclude that the numerical values decrease with decreased sun-spot activity, the year 1883 having been that of sun-spot maximum.

38. *Passing next to the potential gradients of atmospheric electricity, it is seen that a minimum value (109) in 1914 and a maximum value (130) in 1917 are clearly shown, thus indicating increased potential gradient with increased sun-spot activity.* For further evidence of this indicated fact, the interested reader may be referred to my 1921 article.[14]

39. If the phenomena of atmospheric electricity are, indeed, related to solar activity, new points of view as to the origin and maintenance of the Earth's supposed electric charge are disclosed, as already indicated in my previous papers[15]. Accordingly, a Fourier analysis has been made of the diurnal variation (mean of year) of the atmospheric-electric potential-gradient at Ebro for the whole 11-year series, 1910–1920. The resulting quantities will be found in Table 14, which will require no further explanation, the formulæ used being stated at the head of the table.

It will be noticed that the analysis was extended to the sixth term (4-hour wave) inclusive, as for each year a marked increase in the amplitude, c, of the fourth term (6-hour wave) was unmistakably shown. The minimum amplitude, c_1, of the 24-hour wave, occurred in 1912 and the maximum in 1917; the same facts are shown by the amplitude c_4 of the 6-hour wave, which appears to be of extreme interest (see paragraph 28, and values of ϕ_4 for $\triangle Y'$, $\triangle R$, and $\triangle P$, Table 9). The tentatively combined amplitude, c_r, also shows a minimum amplitude in 1912 (one year prior

[14] *Ter. Mag.*, vol. 26, 1921, pp. 63 and 64, and Fig. VII.

[15] *Terr. Mag.*, vol. 25, 1920, pp. 156-162, and vol. 26, 1921, pp. 33-42, and 67-68,

to that of sun-spot minimum) and a maximum amplitude in 1917 (year of sun-spot maximum). *There can hardly be any question, therefore, that the atmospheric-electric potential-gradient at Ebro is subject to a diurnal fluctuation, the amplitude of which increases, as in the case of that of earth currents and terrestrial magnetism, with increased sun-spot activity.*

To find relations between atmospheric-electric phenomena and solar activity, it is essential to select a station as free as possible from meteorological disturbing influences. Such a station the Ebro observatory appears to be.

TABLE 14—*Fourier Analysis of diurnal variation of potential gradient (P) at Observatorio del Ebro, Tortosa, Spain, 1910–1920, for the electrically-undisturbed days (character 0, 1).*

$\triangle P = a_1 \cos \theta + b_1 \sin \theta + a_2 \cos 2\theta + b_2 \sin 2\theta \ldots\ldots = c_1 \sin(\theta + \phi_1) + c_2 \sin(2\theta + \phi_2) \ldots$; θ is counted from 0^h, midnight, G. M. T.

$$c_r = \sqrt{c_1^2 + c_2^2 + c_3^2 + c_4^2 + c_5^2 + c_6^2}$$

Quant.	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	Mean
	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m	V/m
c_1	17.2	16.3	*14.6*	18.0	18.0	18.7	16.4	**23.4**	20.8	17.3	20.9	18.2
c_2	11.7	17.9	14.5	14.7	14.3	17.4	15.7	16.6	15.3	15.4	15.4	15.3
c_3	3.0	1.6	1.5	1.7	3.5	4.2	2.0	2.2	3.5	1.2	5.6	2.5
c_4	7.0	6.4	*5.2*	5.8	6.0	6.4	7.1	**8.3**	6.2	5.6	6.0	6.4
c_5	0.5	1.0	1.3	1.6	0.7	1.8	2.3	1.8	2.2	0.9	2.4	1.3
c_6	2.3	2.3	1.3	1.8	1.5	0.7	2.1	1.7	0.6	1.2	0.7	1.4
c_r	22.3	25.2	*21.4*	24.1	24.1	26.7	24.0	**30.0**	26.9	23.9	27.3	24.8
	°	°	°	°	°	°	°	°	°	°	°	°
ϕ_1	196	202	208	213	212	204	209	211	211	212	213	209
ϕ_2	199	194	190	192	186	193	199	207	196	185	190	194
ϕ_3	282	248	260	286	252	294	255	313	304	282	310	286
ϕ_4	326	330	334	329	326	332	336	334	325	324	325	329
ϕ_5	351	139	153	130	70	79	117	115	124	102	95	112
ϕ_6	92	100	122	98	77	104	97	108	50	90	70	95

Chief Conclusions.

40. With the aid of the highly valuable and promptly published series of observations of earth currents, terrestrial magnetism; and of the atmospheric-electric elements, made at the Observatorio del Ebro, Tortosa, Spain, for a complete sun-spot cycle, it has been possible not only to confirm and extend certain results previously reached by others, but also to draw important new conclusions. The successive directors and members of the scientific staff of the Observatorio del Ebro deserve great credit for making readily accessible the results of their comprehensive and valuable observa-

tional work in geophysics and astrophysics. For the first time it has been possible to make comparisons between the phenomena of terrestrial magnetism, earth currents, and atmospheric electricity, as observed at the same station.

The author also wishes to acknowledge his indebtedness to members of the computing staff of the Department of Terrestrial Magnetism, especially to Messrs. Duvall, Ennis, and Peters, and to Miss Tibbetts; without their effective cooperation the extensive computational work required could not have been so expeditiously accomplished. To Mr. Ennis also must be given credit for the preparation of the diagrams appearing in this paper.

It is hoped that the present investigation, which had to be confined to a discussion of the observational data on magnetically-calm, or on electrically-calm days, may be supplemented later by a discussion of earth-current data on disturbed days.

The chief conclusions may be stated as follows:

a. The resultant horizontal earth-currents, as observed at the Ebro Observatory, flow, on the average for the year, in the direction from about 29° west of North to 29° east of South, or, approximately, in the direction from the Magnetic North Pole towards south-southeast (paragraph 11). The average value, for the magnetically-calm days during 1914–1918, of the potential gradient of the component of the current flowing from true North to South was 0.20 volt per kilometer, and that of the component towards geographic East was 0.11 volt per kilometer, or about one-half of the north-south component. The resultant horizontal potential-gradient was 0.23 volt per kilometer, which during electric or magnetic storms may reach a value 0.8 to 1.0 volt per kilometer (paragraphs 10, 11, and 15).

b. The annual variations of the earth-current potential-gradients and of the components of the Earth's magnetism, as observed at the Ebro Observatory, may be related to one another as cause and effect only to a very minor extent; both sets of variations may have to be referred, more or less, to common causes. (Paragraph 18). The range of the annual variation of the north-south electric component is about 2.5 times that of the west-east component. (Table 6; Fig. 1.)

c. The diurnal variation of earth currents as observed at the Ebro Observatory along lines somewhat over one kilometer long is remarkably similar to that observed at Berlin along telegraph lines, 120 and 262 kilometers in length, from 1884–1887 (Tables 8 and 9, and paragraph 25; Fig. 9). In both cases the diurnal variations for the component of the current along the meridian is considerably more pronounced (2–3 times) than that along the parallel of latitude. The diurnal variation in the north component of the

Earth's magnetism is not such as to correspond to the direct magnetic effect of the diurnal variation of the west-east component of the earth currents. A similar conclusion had to be reached with regard to the east component of the Earth's magnetism and the north-south component of the earth currents. The general conclusion was that the north-south earth-current might be the result of electro-magnetic induction, caused by the fluctuation during the day of the west-east component of the Earth's magnetism (Paragraph 22; Figs. 2 and 3). If it be recalled that all analyses of the diurnal variation field of the Earth's magnetism have shown that the magnetic diurnal variation is in part to be ascribed to electric currents circulating in the regions overhead and in part to currents circulating within the Earth's crust, exact agreements between magnetic variations and earth-current variations are not to be expected. It further remains to point out that until we have some knowledge of the actual course or distribution of the earth currents in the Earth's crust and as to how the conductivity of the crust may vary with temperature and other meteorological causes during the day and at the actual place of observation, attempts to find a quantitative relationship between terrestrial-magnetic and earth-electric effects may be futile.

d. The horizontal vector-diagrams both for the magnetic and earth-electric components vary during the sun-spot cycle in about the same proportion. The earth-current vector-diagram is symmetrical about a line approximately in the direction of the Magnetic North Pole. (See Paragraph 24; Figs. 5 and 7.)

e. The extreme diurnal range of the Ebro earth currents reaches its highest values near the equinoctial months, and lowest near the solstitial months. Earth currents, atmospheric electricity, the Aurora Borealis, and the Earth's magnetic disturbances, all show similar annual variations in the ranges of their fluctuations (Paragraphs 30–33; Fig. 10).

f. The potential gradients of earth currents and of atmospheric electricity apparently vary during the sun-spot cycle, the former decreasing in the direction of normal flow of current, and the latter increasing with increased sun-spot activity (Paragraphs 35 and 39). The diurnal ranges of the potential gradients of earth currents, as well as of atmospheric electricity, just as is the case for the diurnal variation of terrestrial magnetism, increase with increased sun-spot activity (Paragraphs 30 and 39).

g. There is evidence of a similar six-hour wave in atmospheric electricity, earth currents and terrestrial magnetism (Paragraph 39).

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NOTE ON A SIMPLE MEASURE OF THE EARTH'S DAILY MAGNETIC ACTIVITY.

By Louis A. Bauer.

In a timely paper[1] for the Rome meeting of the International Section of Terrestrial Magnetism and Electricity, Dr. G. van Dijk, of the De Bilt Observatory, makes a very desirable comparison, chiefly for the year 1915, of measures of terrestrial magnetic activity proposed by various investigators. For the various measures, designated below, the following symbols are used here: D, magnetic declination; H, horizontal intensity; Z, vertical intensity; R, absolute diurnal range, or difference between extreme daily values of element considered; and A, diurnal range of hourly values (mean value over 60-minute interval).

Quantity	Proposer and Institution	Designation
$A_h^x + A_d^h = A_d^x$	Bidlingmaier, Wilhelmshaven Observatory	Bi.
$\frac{1}{100}\,\Sigma(R_D^2 + R_H^2 + R_Z^2) = \Sigma R^2$	Chree, Kew Observatory	Ch.
$\Sigma(A_D + A_H + A_Z) = \Sigma A$	Schmidt, Potsdam Observatory	Sh.
$\Sigma(R_D + R_H + R_Z) = \Sigma R$	van Dijk, De Bilt Observatory	Di.
$\epsilon.\, H\, R_H$	Bauer, Department of Terrestrial Magnetism	Ba.
$\Sigma(\text{Mag. Char. Nos.}) = \Sigma C$	Magnetic Commission, International Meteorological Committee	Me.

If at any observatory the diurnal ranges of D and H are not available, then those of the rectangular components X and Y are to be used. In the second, third, and fourth measures the D-range is to be expressed in gammas, namely, $H\,R_D$.

Every one must feel indebted to Dr. van Dijk for having published the values of the above measures for each day of 1915, for the De Bilt Observatory, thus facilitating a fair comparison. Table 1 gives the mean monthly values as derived from van Dijk's tables, in which any unessential decimals have been omitted and the following additional columns have been added: SN, final sun-spot numbers according to Wolfer; SD, sun-spot departures or D-measures[2] of solar activity based on SN; and SP, mean daily prominence-

[1] Activity of the Earth's magnetism and magnetic characterization of days, *Ned. Med. Inst.*, No. 102, Utrecht, 1922.

[2] Bauer, L. A., *Terr. Mag.* vol. 26, p. 47.

areas observed at Kodaikanal, India, according to manuscript values courteously supplied by Evershed, October 19, 1921.

Fig. 1 shows the 9 curves based upon the data in Table 1. An inspection immediately shows a pronounced crest in June for all magnetic measures (Curves 2–6), excepting for the character numbers (Curve 9). This June crest in the magnetic curves occurs one month earlier than the crest in the sun-spot curve (No. 1); it, however, occurs in the same month (June) as does the crest in the *D*-measure of solar activity (Curve 7).[3] For Curve 3 (Ch-measure) the peak is most pronounced because of the method of computation in which the *squares* of the ranges of the diurnal variation are used. It may thus happen for this measure, that, as in the case of the Bi-measure, a few days of large disturbance, or

Table 1. *Monthly mean measures of daily magnetic activity based on the De Bilt magnetic observations for 1915*

Month	S.N.	Bi	Ch	Sh	Di	Ba	S.D.	S.P.	Me
Jan	*23.0*	*8.1*	*66*	*73*	*110*	*7.9*	*8.3*	4.4	18.6
Feb	42.3	13.6	97	97	142	9.0	23.1	3.9	22.5
Mar	38.8	24.6	163	141	190	13.1	18.4	7.1	**23.8**
Apr	41.3	26.8	156	143	189	12.1	20.4	6.1	21.4
May	33.0	23.1	124	134	171	11.4	26.4	5.6	20.5
Jun	68.8	**53.8**	**361**	**173**	**224**	**16.1**	**49.0**	3.8	21.4
Jul	**71.6**	31.4	*148*	*158*	*190*	13.0	28.1	3.6	*16.5*
Aug	69.6	32.4	158	160	205	13.7	21.8	6.0	21.1
Sep	*49.5*	*29.8*	190	149	203	13.1	*16.9*	4.8	20.6
Oct	**53.5**	**38.4**	288	**159**	**233**	14.6	**19.8**	6.7	27.0
Nov	42.5	32.6	**299**	140	224	**16.1**	11.1	4.4	**28.9**
Dec	34.5	14.5	121	83	132	9.4	10.5	5.2	18.9
Mean	47.4	27.4	181	134	184	12.5	21.2	5.3	21.8
Curve	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

even but one day, may practically control the value of the measure for the entire month. Take, for example, June 17, 1915, when a very severe magnetic disturbance occurred. According to van Dijk's figures, the various measures contribute the following percentages to their respective monthly means: Bi, 44; Ch, 62; Sh, 15; Di, 20; Ba, 21. It is thus seen that "Ch" was affected most by one-day's severe disturbance, and "Sh" least, which is no doubt chiefly due to the fact that in the computation extreme ranges were not used, as in the case of "Di" and "Ba", but *smoothed* ranges, i. e., ranges from the hourly 60-minute means.

The measures "Bi" and "Ch" may also suffer from the fact that they depend on quadratic formulæ; hence, in order to get their mean values for a month, it is necessary to compute the measures for *each* day. For the linear measures, "Sh", "Di", and "Ba", the mean monthly measure may be derived directly from the difference between the monthly mean maximum and minimum values,

[3] See my previous article *Terr. Mag.*, vol. 26, 1921, Fig. V, and explanation, p. 62.

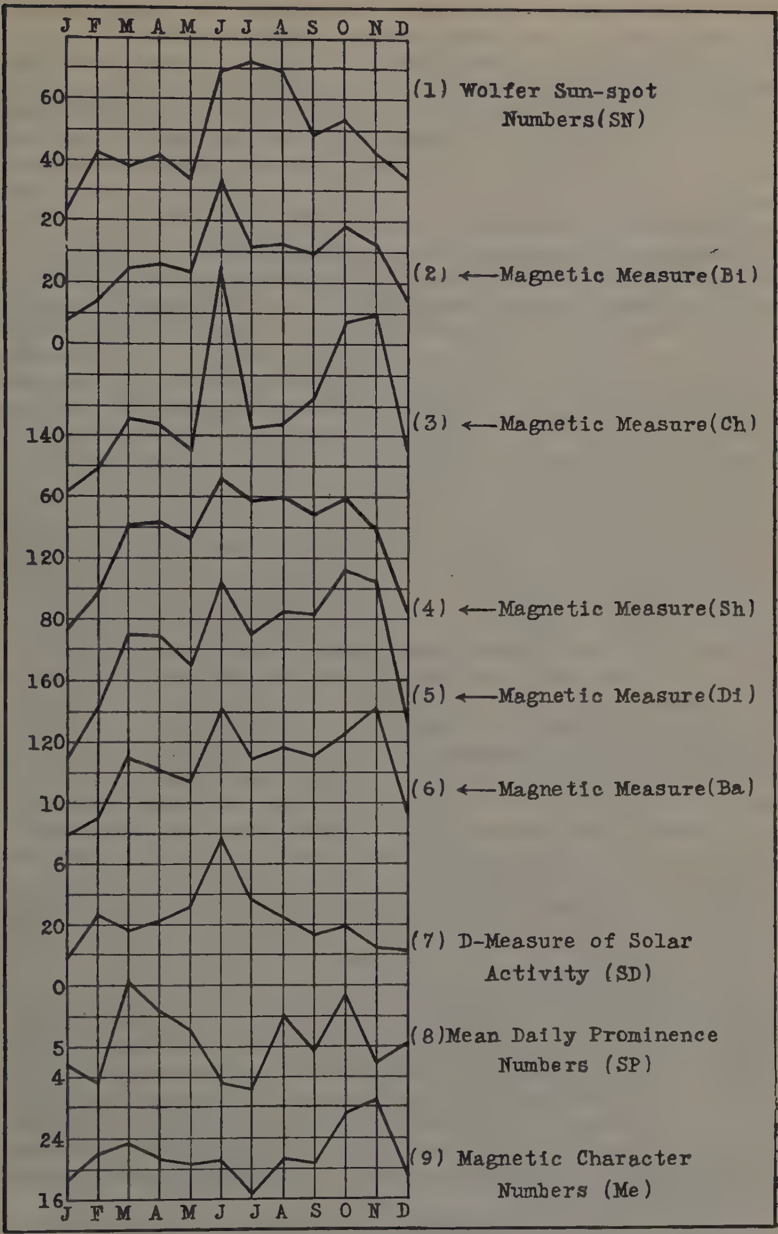


FIG. 1.—Monthly Measures of the Earth's Daily Magnetic Activity for 1915 and the DeBilt Observatory.

and it is, therefore, not necessary to compute the values for each day, unless they are required for some other purpose.

All the magnetic curves (Nos. 2–6) of Fig. 1 show also a pronounced peak, either in October or November, for which no exact counterpart, except to a limited extent, is found in the sun-spot curve (1) and in the D-measure (Curve 7). However, the solar-prominence curve (8) shows a peak in October and the magnetic character numbers, Curve 9, a peak in November; otherwise Curve 9 is the most disappointing one of the magnetic measures, as far as relation with solar activity is concerned. It would appear as though this autumn maximum in the magnetic measures is a striking illustration of an over-developed customary disturbance maximum near the equinoctial months (see also Fig. 10 on page 24 of the present issue of this *Journal*). We have here a class of magnetic disturbances, which cannot be related immediately to sun-spot activity as observed on the disc of the Sun turned at the time towards the Earth. This class must apparently be referred to eruptive matter from solar-prominences and to coronal matter through which the Earth passes in its revolution around the Sun; such cases will be treated at greater length in a future paper.

A further discussion of some of the interesting points raised by van Dijk will have to be postponed at present. It must suffice here to remark that some of the computations made for combined measures, as given, for example, by van Dijk in his Table 5, page 17, I have not advocated for reasons in part stated in paragraphs 23 and 26 of my previous paper[4], and to be more fully set forth in the later paper. When the ranges R_X, R_Y, R_Z, or R_H, and R_Z, must be used instead of the *variations*, dX, dY, dZ, I tentatively restricted my activity measure to $\epsilon H R_H$. There are two obvious numerical errors in the last column of van Dijk's Table 5, page 17, namely, the quantities for August and November should evidently be 23.59 and 16.09, respectively. If these corrections are made, it will be found that the figures derived from my simple measure in which only the H-range is used and given in the first column of van Dijk's table, follow the same course as those from his extended computations (corrected figures of last column), in which the ranges for the three magnetic components are used.

The limitations of the computing personnel at most of the magnetic observatories require that a measure of magnetic activity be used, preferably of the linear type, which can be readily computed and which will be found to be approximately the same at stations in moderate magnetic latitudes all over the Earth. As already intimated, this matter will be treated at further length in a future communication. Evidently the numbers used at present to characterize the magnetic character of a day require early supplementing in some effective manner.

DEPARTMENT OF TERRESTRIAL MAGNETISM,
CARNEGIE INSTITUTION OF WASHINGTON.
April 4, 1922.

[4] *Terr. Mag.*, vol. 26, 1921, pp. 57 and 58.

RESULTS OF MAGNETIC OBSERVATIONS ON THE "MAUD EXPEDITION", 1918–1921.[1]

By H. U. Sverdrup[2] and C. R. Duvall.[3]

Introduction by Roald Amundsen.

In writing a brief introduction to the present publication, I wish to emphasize that the co-operation with the Department of Terrestrial Magnetism of the Carnegie Institution, of Washington, has been of the highest value to the "Maud Expedition." In 1918 the Department of Terrestrial Magnetism made every possible effort to secure for the Expedition, not only the best and most suitable instruments, but also additional equipment which might facilitate the work under the conditions to be encountered. The instruments themselves were successfully modified for use in Arctic regions, and carefully compared with the standards of the Department. The results of the repeated comparisons in 1921 are highly satisfactory, because, according to them the standards of the instruments have remained practically unchanged, thus leaving no doubt as to the reduction of the field observations to the Department's adopted standards.

It must be regarded as very fortunate that the Department of Terrestrial Magnetism found it possible to carry out immediately the computation and reduction of the observations made during the years 1918-1921, and to publish them within eight months after the return of the Expedition, thus preventing them from sharing the fate of so many observations which have not been made available until after many years.

For the future work of the Expedition, it has been of great advantage to have had Dr. H. U. Sverdrup associated with the Department of Terrestrial Magnetism during the past winter at Washington, taking part in the computation of the observations and the comparison of the instruments, which now again are placed at the disposition of the Expedition. The Department of Terrestrial Magnetism has further increased the scientific equipment by the addition of specially designed apparatus for the determination of the atmospheric-electric potential-gradient, and has rendered most valuable assistance in making it possible for the Expedition to obtain instruments for its various researches.

I take great pleasure in availing myself of this opportunity to express my sincere thanks to the Director of the Department of Terrestrial Magnetism, Dr. Louis A. Bauer, and to the Assistant

[1] Full publication will be made in Vol. V, Researches of the Department of Terrestrial Magnetism, Publication 175 of the Carnegie Institution of Washington.

[2] In Charge of the Scientific Work of the Expedition.

[3] Expert Computer, Department of Terrestrial Magnetism.

Director, Mr. J. A. Fleming, under whose supervision, Dr. Bauer informs me, Messrs. Sverdrup and Duvall have prepared the results for publication.

Roald Amundsen

Washington, March 31, 1922.

[The co-operation of the Department of Terrestrial Magnetism with Amundsen's Expedition has proved exceedingly satisfactory and stimulating. Captain Amundsen and Dr. Sverdrup, as well as other members of the Expedition, who participated in the observational work, deserve great credit for the highly successful manner in which their arduous duties under trying conditions were carried out. We confidently look forward to equally successful and valuable results from the future expedition, and wish it godspeed and the best of luck.—Louis A. Bauer.]

INSTRUMENTS AND EQUIPMENT.

As the result of a conference at Washington in April, 1918, between Captain Roald Amundsen, Dr. Fridtjof Nansen, and Dr. Louis A. Bauer, certain minor modifications were decided upon in the instruments to be supplied by the Department of Terrestrial Magnetism for the magnetic observations to be undertaken, in co-operation with the Department, on Captain Amundsen's proposed "Maud Expedition" to the Arctic regions. These modifications, none of which altered the intrinsic design of the instruments, were based upon the considerations resulting particularly from the Arctic experiences of Dr. Nansen, Captain Amundsen, and Mr. Peters of the Department. C. I. W. magnetometer, No. 8, and Dover dip-circle, No. 205, were selected as instruments most nearly answering the requirements specified by Captain Amundsen.[4] The required modifications of instruments were made under the direction of Mr. Fleming in the instrument-shop of the Department.

The accessory equipment supplied by the Department of Terrestrial Magnetism for the magnetic work included: 3 tripods; one for magnetometer 8, one for dip circle 205, and the third for use in connection with astronomical observations; 3 magnetic observing tents, containing no iron fastenings of any kind; 3 good

[4] *Cf.* Vol. IV, Researches of Department of Terrestrial Magnetism, 1921, p. 8, and Pl. 2 showing the instruments.

watches; miscellaneous tools, materials, etc.; accessories of various kinds; forms for recording magnetic observations of various kinds, together with some forms for astronomical observations and miscellaneous purposes; miscellaneous scientific books; complete instructions for observations with the different instruments and special instructions for magnetic work in the Arctic.

In addition to the instruments loaned by the Department of Terrestrial Magnetism, the Expedition had also Dover land dip-circle, No. 154, with one pair of dip needles (Nos. 1 and 2), and a photographic registering declinometer, made by Max Toepfer and Son, Potsdam. Registering magnetic instruments were generally not included in the equipment of the Expedition, because in the drifting ice it would not be possible to use them on account of the perpetual movements of the ice, but this declinometer, which was the property of the Expedition, was taken along in the expectation that it might be used at occasional shore stations, e. g., at winter quarters (see page 38).

For astronomical work the Expedition had 3 sextants, 5 theodolites of different sizes, 3 chronometers, and 15 watches (inclusive of 3 supplied by the Department of Terrestrial Magnetism).

METHODS OF OBSERVING.

The magnetic observations were made in accordance with the instructions supplied by the Department of Terrestrial Magnetism. The methods used are given in detail in Volumes I, II, and IV of the *Researches* of the Department (see particularly pp. 13-41, and specimen observations, Vol. I). The experiences encountered by the observers of the Expedition while making magnetic observations in the Arctic do not differ essentially from those of observers on former expeditions; however, they will be found in the fuller publication.

Observatory Work.—At the end of September, 1918, a magnetic observatory was built on shore at winter quarters (Station No. 4). It was built of drift-wood logs and planks, with wooden or copper nails, and was, therefore, perfectly non-magnetic. To keep the temperature as high as possible, the inside was lined with canvas, and snow was thrown over the house. Because of the insulating power of the snow, the temperature in the observatory only accasionally sank below —25° C, while outdoors it might be as cold as about —40° for weeks at a time. The dimensions of the observatory were 3 by 4 meters, and the height, to the ridge-pole, 2.8 meters. In the room two wooden piers were placed at a distance

apart of 1.8 meters. They were driven as far down in the ground as the frost permitted, and had no connection with the floor. The magnetometer was placed on the front pier, and the dip circle on the back pier. During observations, all magnets not in use were placed on a snow pillar 10 meters in front of the house. Both instruments were permanently installed by the end of November.

During the winter, the observatory was lighted by a gaslight lamp of the "Lux" pattern, which also develops considerable heat, all iron parts of the lamp having been removed, and replaced with parts of copper or brass. The vernier readings were made by means of small electric lamps, the current being supplied by a dry cell battery which had to be taken on board after each observation in order not to get too cold. The same battery was also used for illuminating the mark for declination observations, which was used in the dark season. This mark was simply a small electric lamp which was fastened on top of a stick in front of the observatory, and could be lighted from the inside of the observatory. During the period of daylight, a pole placed in a cairn at about 600 meters distance was used as a mark.

The observatory house was torn down on April 1, 1919, and a square tent, 2 by 2 meters, made of light canvas, was placed on the wooden floor; thus no artificial illumination was needed. At this season the tent had the advantage of being much warmer than the house. Even on a wholly overcast day the temperature inside the tent might be 10° C higher than outside, while on a clear day with sunshine the temperature might be 25° C higher.

Some trouble was anticipated in the behavior of the watches at low temperatures. It was found that some of the watches, perhaps on account of the quality of the oil used in them, behaved very satisfactorily despite the great changes in temperature.

That magnetic disturbances often caused difficulties need hardly be mentioned. Sometimes the disturbances were so violent that the observations had to be broken off because the magnet disappeared from the field of view time after time.

During the winter of 1918–1919, the photographic declinometer was mounted in a long, low building attached to the observatory, from which it could be entered. The whole building was buried in snow, so the temperature did not sink below —20° C in the registering room. In spite of this, it was not possible at first to make the clock which drives the drum work properly, but this difficulty was overcome by removing all oil by means of a benzine bath and then applying a small quantity of kerosene as lubricant. The registra-

tions were kept up from November 10, 1918, to July 31, 1919, with only occasional interruptions, but, unfortunately, the traces, together with all meteorological and tidal registrations, have been lost (see page 49).

Field Work.—The general experience on this Expedition was that magnetic field work in the Arctic can only be carried out successfully in spring and summer. In the fall and in the winter much bad weather and short daylight make it almost impossible to take magnetic observations in the field, even though it is feasible to travel in these seasons.

The kinds of instruments which may be used in the field depend upon the means of transportation. If the observer travels with reindeer, an ordinary field equipment, including an observing tent, may be taken along, so the conditions in the favorable seasons will be the same as for ordinary field work. But for travel with dog sledges the conditions are different and ordinarily the weight of equipment carried has to be reduced as much as possible. The most suitable instrument for carrying on a dog sledge is the dip circle with compass attachment, but without tripod.

In the spring of 1919 a special program was decided upon to insure obtaining approximately simultaneous observations at field stations and at the winter-quarters station. This scheme was carried out for the work in 1919, but could not be kept up in the two following years; in 1920 all instruments were used for field work, and in 1921 there was a lack of observers.

It will be noted from Table 1 that no declinations were determined at most of the field stations. This was because Messrs. Wisting and Hanssen were unfamiliar with use of the theodolite for determination of azimuth. During January, 1922, the peep-sights of the compass attachment were modified in the instrument shop of the Department of Terrestrial Magnetism in such a way that it will be possible to sight the Sun directly, or to use a shadow-method for determination of azimuth in future work. If, in addition, a sextant observation for local time is made, the true azimuth of the Sun may be computed, and thus all necessary data for determination of the declination will be available.

INSTRUMENTAL CONSTANTS AND REDUCTIONS TO STANDARD INSTRUMENTS.

The instrumental constants and corrections for the various magnetic instruments depend chiefly upon observations at Washington, before and after the field work, and, in part, upon the observers' intercomparisons in the field.

The International Magnetic Standards (designated I. M. S.), as defined in Volume II of the "Researches of the Department of Terrestrial Magnetism", pages 211 to 278 (see also Volume IV, pp. 395–475), have been adopted for the results given in Table 1.

EXPLANATORY REMARKS FOR TABLE 1.

Precisely the same conventions have been followed in the presentation of the field results obtained during the four years 1918 to 1921, as adopted in Volumes I, II, and IV, of the "Researches of the Department of Terrestrial Magnetism". These conventions, briefly recapitulated, are as given in the following paragraphs:

It has not been deemed advisable to attempt at present to apply corrections to the observed results on account of the numerous variations of the Earth's magnetism, e. g., diurnal variation, secular variation, magnetic perturbations, etc. Instead, it is believed to be better to publish the observed results as obtained, with no corrections applied, except the reductions to the magnetic standards of the Department, as already explained. The reduction to a common epoch will be undertaken by the Department later. It will be noticed, however, that opposite the magnetic elements appearing in the table, the precise date and local mean time are given, thus supplying the required information for reducing the observed values to some mean period. The tabular entries are in the order of decreasing north latitude.

The question whether to give values of horizontal intensity exclusively or values of total intensity was decided in favor of the former.

The intensities are published in C. G. S. units. The fourth decimal may be frequently uncertain by one or more units. It will be noted that the values are given to the fifth decimal, but it should be understood that no claim is made as to the correctness of the last figure; the last figure is retained primarily in order that when all reductions to epoch have been applied on account of the magnetic variations an error of a unit in the fourth decimal, due purely to computation, will not enter.

The headings for the columns of the table are self-explanatory. The following abbreviations have been adopted for the months of the year: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec. For stations near the meridian 180° east of Greenwich the dates are reckoned from that meridian without regard to the International Date Line. Local mean times are expressed to the nearest 0.1 of an hour of each value, and are given according to

TABLE 1.—*Results of Magnetic Observations, 1918–1921, on the "Maud Expedition."*

ASIA.

SIBERIA.

Station	Latitude	Long. East of Gr.	Date	Declination L. M. T.	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value
	° ′	° ′		h	° ′	h	° ′	h	c.g.s.
No. 14	78 09 N	106 05	Apr 21, '19	...	...	16.9	85 30.2 N	...	...
No. 15	78 06 N	106 45	Apr 23, 19	...	...	15.5	85 38.6 N	...	...
No. 5	77 42 N	103 55	Apr 4, 21, 19	...	...	16.6 (2)	85 26.3 N	16.6 (2)	.04588
No. 16 (Lockwood Islands)	77 35.5 N	105 29	Jul 15, 19	...	...	16.4 (2)	85 32.1 N	16.4 (2)	.04557
No. 17 (Fram Island)	77 33.8 N	105 43	Jul 17, 19	...	...	16.0 (2)	85 32.6 N	16.0 (2)	.04556
No. 19	77 33.2 N	105 32	Jul 19, 19	...	...	11.4 (2)	85 33.0 N	11.4 (2)	.04534
No. 4 Winter Quarters, 1918-1919	77 32.6 N	105 40	Oct 18	13.1 (8)	26 33.3 E	12.5 (4)	85 33.0 N	13.6 (11)	.04557
			Nov 18	11.1 (2)	26 56.6 E	12.4 (9)	85 30.8 N	13.3 (12)	.04583
			Dec 18	12.9 (37)	26 38.9 E	14.2 (26)	85 30.7 N	13.0 (45)	.04575
			Jan 19	10.7 (23)	26 41.0 E	15.5 (16)	85 32.6 N	14.1 (16)	.04548
			Feb 19	12.4 (13)	26 32.6 E	15.6 (19)	85 31.4 N	15.4 (25)	.04584
			Mar 19	13.3 (9)	26 50.4 E	12.5 (13)	85 34.5 N	13.4 (9)	.04543
			Apr 19	15.4 (20)	26 22.0 E	...	...	15.6 (20)	.04613
			May 19	10.7 (23)	27 09.4 E	...	...	10.9 (19)	.04518
			Jun 19	10.9 (16)	26 57.5 E	...	...	10.8 (16)	.04518
			Jul 19	13.7 (27)	26 22.8 E	...	...	13.7 (27)	.04558
			Aug 19	13.9 (3)	26 39.6 E	...	...	16.0 (2)	.04532
No. 4b Winter Quarters, 1918-1919	77 32.6 N	105 40	Mar 19	...	...	12.4 (14)	85 34.2 N	12.2 (12)	.04523
			Apr 19	...	...	15.4 (8)	85 31.3 N	13.7 (2)	.04534
No. 4c Winter Quarters, 1918-1919	77 32.6 N	105 40	Apr 19	...	...	11.4	85 35.0 N	...	...
			May 19	...	...	11.3 (2)	85 34.8 N	11.3 (2)	.04511
			Jul 19	...	...	12.4 (8)	85 31.5 N	12.4 (8)	.04562
			Aug 19	...	...	15.7	85 32.5 N	15.7	.04543
No. 20	77 32.1 N	105 45	Jul 21, 19	...	...	15.8 (2)	85 30.2 N	15.8 (2)	.04610
No. 6	77 32 N	102 44	Apr 7, 19	...	...	16.7	85 25.5 N	16.7	.04673
No. 18	77 30.2 N	105 34	Jul 18, 19	...	...	16.4 (2)	85 00.0 N	16.4 (2)	.05130
No. 8	77 16 N	101 45	Apr 19, 19	...	...	16.0	85 09.4 N	16.0	.04967
No. 13	77 05 N	106 21	May 24, 19	...	...	10.6	85 24.0 N	10.6	.04712
No. 12	76 43 N	107 03	May 21, 19	...	...	11.1	85 15.5 N	11.1	.04863
No. 9	76 34 N	102 47	May 14, 19	...	...	11.4	84 59.7 N	11.5	.05125
No. 7	76 32 N	101 15	Apr 14, 19	...	...	16.9	85 03.0 N	16.9	.05072
No. 11	76 31 N	106 13	May 20, 19	...	...	11.8	85 15.6 N	11.8	.04856
No. 10	76 05 N	104 11	May 16, 19	...	...	11.4	85 03.5 N	11.4	.05070
No. 3 (Port Dickson)	73 30.2 N	80 26	Sep 2, 3, 18	17.0 (3)	28 43 E	19.4	82 37.7 N	18.6 (3)	.07503
No. 32	70 03 N	171 15	Jun 8, 20	...	...	12.6	78 20.4 N	12.7	.11580
No. 33	69 56 N	170 35	Jun 12, 20	...	...	3.0	78 23.3 N	3.0	.11525
No. 31	69 54 N	173 30	Jun 6, 20	...	...	3.4	78 18.0 N	3.4	.11585
No. 21 (Ayon Island), Winter Quarters, 1919-1920	69 52.5 N	167 43	Oct 29, 19	...	...	11.1	78 20.9 N	11.1	.11583
			Nov 19	...	...	11.5 (3)	78 21.4 N	11.5 (2)	.11590
			Jun 18, 20	...	...	12.0 (2)	78 21.6 N	11.3	.11551
No. 40 (Ayon Island)	69 51.2 N	167 57	Jun 16, 17, 20	16.0 (4)	3 26.5 E	17.9 (2)	78 19.7 N	16.1 (4)	.11627
No 30	69 50 N	176 30	Jun 4, 20	...	...	3.9	78 07.4 N	3.9	.11741
No. 29	69 27 N	178 35	Jun 2, 20	...	...	4.3	77 56.0 N	4.3	.11895
No. 39	69 00.8 N	167 04	May 7, 20	11.5	2 25.5 E	17.1	77 36.1 N	13.7 (2)	.12254
No. 28	68 55 N	179 29	May 31, 20	...	...	6.3	77 30.8 N	6.3	12277
No. 37	68 36.7 N	163 45	Apr 11, 12, 20	12.6 (4)	0 09.4 W	13.3	77 32.4 N	15.0 (2)	.12384
No. 36 (Panteleika)	68 36.1 N	161 55	Apr 1, 2, 20	13.2 (4)	1 16.7 W	17.0 (2)	77 48.7 N	13.3 (4)	.12036
No. 34	68 36 N	166 00	Nov 5, 6, 19	...	...	14.4	77 33.5 N	12.1 (3)	.12301
No. 38	68 34.3 N	165 56	Apr 28, 20	10.2 (2)	1 13.5 E	13.6	77 32.8 N	10.3 (2)	.12389
No. 27	68 18 N	182 20	May 27, 20	...	...	15.4	77 06.1 N	15.4	.12631

ASIA.

Siberia—*Concluded.*

Station	Latitude	Long. East of Gr.	Date	Declination L. M. T	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value
	°	°		h	° ′	h	° ′	h	c.g.s.
No 35	68 13.6 N	164 52	Dec 24,31'19	11.9 (3)	0 45.2 E			11.8	.12732
			Jan 20	11.6 (5)	0 49.0 E	12.5 (3)	77 09.0 N	11.8 (5)	.12733
			Feb 20	12.1 (7)	0 47.8 E	14.8 (2)	77 10.3 N	13.6 (8)	.12732
			Mar 3 20	11.8 (2)	0 50.3 E	15.0	77 09.0 N	11.8 (2)	.12727
No. 26	67 49 N	184 10	May 25, 20			12.5	76 40.8 N	12.5	.13047
No. 25	67 15 N	185 20	May 24, 20			18.3	76 16.5 N	18.3	13450
No. 53 (Pitlekai)	67 06.3 N	186 29	Apr 13, 21	13.6 (2)	15 03 E	13.7	76 26.2 N	13.7	.13213
No. 24	67 01 N	187 45	May 22, 20			15.4	76 12.9 N	15.4	.13409
No. 41 (Cape Serdze Kamen), Winter Quarters, 1920-1921	66 53.2 N	188 21	Nov 29, 20					12.2 (2)	.13394
			Dec 20			11.8 (3)	76 13.7 N	11.7 (4)	.13394
No. 41b (Cape Serdze Kamen), Winter Quarters, 1920-1921	66 53.0 N	188 21	Jan 21	11.8 (9)	16 35 E	12.3 (4)	76 15.5 N	12.3 (8)	.13351
No. 41c (Cape Serdze Kamen)	66 53.0 N	188 21	Apr 26, 21	15.2 (2)	16 39.2 E			15.1 (2)	.13344
No. 41d (Cape Serdze Kamen)	66 53.0 N	188 21	Apr 26, 21	15.6 (2)	16 40 E	15.8 (2)	76 16.6 N	15.7 (2)	.13334
No. 23	66 32 N	189 00	May 18, 20			16.5	76 06.0 N	16.5	.13509
No 51	66 10 N	183 50	Mar 15, 21	12.3	13 29 E	13.0	75 35.7 N	13.0	.13949
No. 22 (Kain-ge-skon)	66 03 N	189 50	Mar 20			12.9 (4)	75 37.0 N	12.9 (4)	.13930
			Apr 20			13.0 (5)	75 36.5 N	13.1 (5)	.13931
No. 42 (Kain-ge-skon)	66 03 N	189 50	Feb 4, 21	11.0	17 33 E	12.4	75 40.2 N	12.4	.13819
No. 50	65 39 N	183 06	Mar 13, 21			7.5	74 56.5 N	7.5	.14476
No. 49 (Mass-kan)	65 31.2 N	181 25	Mar 8, 21	11.6 (2)	10 09 E	11.7	74 59.2 N	11.7	.14460
No. 43 (Yan-dang-ai)	65 30 N	188 55	Feb 9 21	10.3	15 16 E	11.4	75 09.5 N	11.4	.14266
No. 52	65 28 N	185 55	Mar 29, 21			12.6	75 05.5 N	12.6	.14334
No. 48 (An-ma-la)	65 01.4 N	184 12	Mar 21	13.8 (2)	11 34 E	13.4 (3)	74 15.7 N	13.4 (3)	15092
No. 44 (Jan-da-ken-nut)	64 54 N	187 25	Feb 14, 21	10.5 (2)	16 04 E	10.5	74 40.1 N	10.5	.14772
No. 47	64 50 N	185 25	Feb 23, 21			12.3	74 26.3 N	12.3	.14905
No. 45 (Nabba-kotta)	64 34 N	187 28	Feb 17, 21			13.9	74 24.9 N	14.0	.14861
No 46 (Emma Harbor)	64 24 N	186 48	Feb 20, 21	13.9 (2)	14 29 E	13.9	74 13.9 N	13.9	.15040

EUROPE.

Russia.

Station	Latitude	Long. East of Gr.	Date	Declination L. M. T	Declination Value	Inclination L. M. T.	Inclination Value	Hor. Intensity L. M. T.	Hor. Intensity Value
	° ′	° ′		h	° ′	h	° ′	h	c.g.s.
No. 1 (Vaigach)	69 41.5 N	60 12	Aug 12,13'18	14.4 (3)	20 13.7 E	12.0	78 40.8 N	15.2 (3)	.10901
No. 2 (Khabarowa)	69 39.8 N	60 24	Aug 15, 18	14.2 (3)	19 54.5 E	17.6	78 37.4 N	14.7 (3)	.10920

civil reckoning, being counted from midnight as zero hour continuously through 24 hours; 16^h, for example, means 4 o'clock p. m. The declination and inclination values are, in general, given in degrees, minutes, and tenths of minute of arc. The values of declination resulting from compass observations are given to the nearest minute only, as the results cannot be considered of greater precision than the nearest minute.

In the present condensed table the results of the observations at winter quarters, for example, are not given in detail, as will be

done in the fuller publication; instead, they have been summarized, the numeral in parentheses indicating the number of days on which observations were made for the designated interval.

Besides Captain Amundsen and Dr. Sverdrup, those participating in the observational work were Messrs. H. Hanssen, P. Knudsen, and O. Wisting.

A large part of the original computations was carried out in the field by Dr. Sverdrup. The final computations and revisions were made by the authors with some assistance from Mr. H. W. Fisk, of the Department of Terrestrial Magnetism.[1] Subsequent to our revisions of the results, the data from independent computations of the astronomical observations of 1920, as carried out at the Astronomical Observatory of the University of Christiania under the direction of Professor J. Fr. Schroeter, were received; these results agreed with the original astronomical computations thus serving as an additional check.

DISTRIBUTION AND GEOGRAPHIC POSITIONS OF STATIONS.

Fig. No. 1 shows the route of the *Maud* from Norway to Bering Strait. Figs. Nos. 2, 3, and 4 show the positions of the stations on the Chelyuskin and Chukotsk peninsulas. Three of the stations, Nos. 4, 21, and 41, are close to the winter quarters of the *Maud* during the winters 1918-1919, 1919-1920, and 1920-1921, respectively. For these stations, the latitude has been determined with an accuracy of $0'.1$. The values of the longitudes are probably accurate within $2'$ of longitude more or less. They have been determined by means of chronometers whose corrections on Greenwich mean time were obtained by time signals before the departure from Norway on July 15, 1918, and on the arrival in Nome on August 4 and 6, 1920, and whose rates had been ascertained by numerous observations at the winter quarters. At station No. 4 the longitude determinations by means of the chronometers were checked by observations of the Moon. At stations Nos. 21 and 41 the agreement between the determinations of the Expedition and the longitudes derived from the chart of the north coast of Siberia, issued by the Russian Department of Marine (Hydrographic Division) in 1914, is a good check. This chart is corrected according to the results from the Russian Hydrographic Expedition to the Arctic Sea by the ice-breakers *Taymyr* and *Vaigach*, in 1911 to 1913, and is very reliable according to the experience of the Expedition.

[1] Dr. Sverdrup was associated with the Department of Terrestrial Magnetism at Washington from October, 1921, to March, 1922.

The positions of stations Nos. 5 to 15 on Chelyuskin Peninsula and Crown Prince Alexei Islands are all derived from sextant observations which have been checked by the dead reckoning kept on the sledge-trips. The latitudes therefore are accurate within less than 1′, but errors in the longitudes, which depend upon the rates of the watches used, may be larger. The longitudes are all computed on the assumption that the adopted value for station No. 4, viz., 105° 40′ E, is correct.

The positions of stations Nos. 16 to 20, in the vicinity of station 4, have been obtained by a simple triangulation.

For stations Nos. 22 to 33, along the north coast of Siberia from Bering Strait to Ayon Island, the positions have been derived from the Russian chart of the coast, which has already been mentioned. On the sledge-trip during which these stations were occupied, a distance-wheel was always used, connected with the sledge. At places which were difficult to identify on the map, the distance, according to the distance-wheel, from the nearest conspicuous point was used to find the position. The positions thus obtained have probably no greater errors than about 1′ in latitude and 3′ to 4′ in longitude.

At stations Nos. 34 to 40, astronomical observations were made by theodolite. The errors in the latitudes, therefore, are not more than 0′.5, but the error in the longitudes may be larger, because the longitudes depend upon watches which were carried in the field for seven and one-half months. However, numerous observations made at the same stations from time to time, at intervals of about six days, show that the one watch which was always carried on the body of the observer kept the rate astonishingly well, so the longitudes are certainly not more than 5′ wrong.

At stations Nos. 42 to 53, the values of latitude and longitude have been partly taken from the Russian map of the coast and partly determined by observations. The positions observed by the Expedition show this map to be reliable along the east coast of the Chukotsk Peninsula, and along the south coast as far as Cape Bering; west of Cape Bering, however, it is inaccurate.

NARRATIVE OF THE EXPEDITION WITH REFERENCE PARTICULARLY TO THE MAGNETIC OBSERVATIONS, 1918–1921.

The "Maud Expedition" left Norway in July, 1918, with a total personnel of ten men. Captain Amundsen's plan was to follow the Russian and Siberian coasts eastward to about 165° east longitude, to penetrate as far north as possible in this longitude, let his vessel,

FIG. 1.—Map of Arctic Regions, showing Route and the three Winter-Quarters of the "Maud Expedition," 1918-1921.

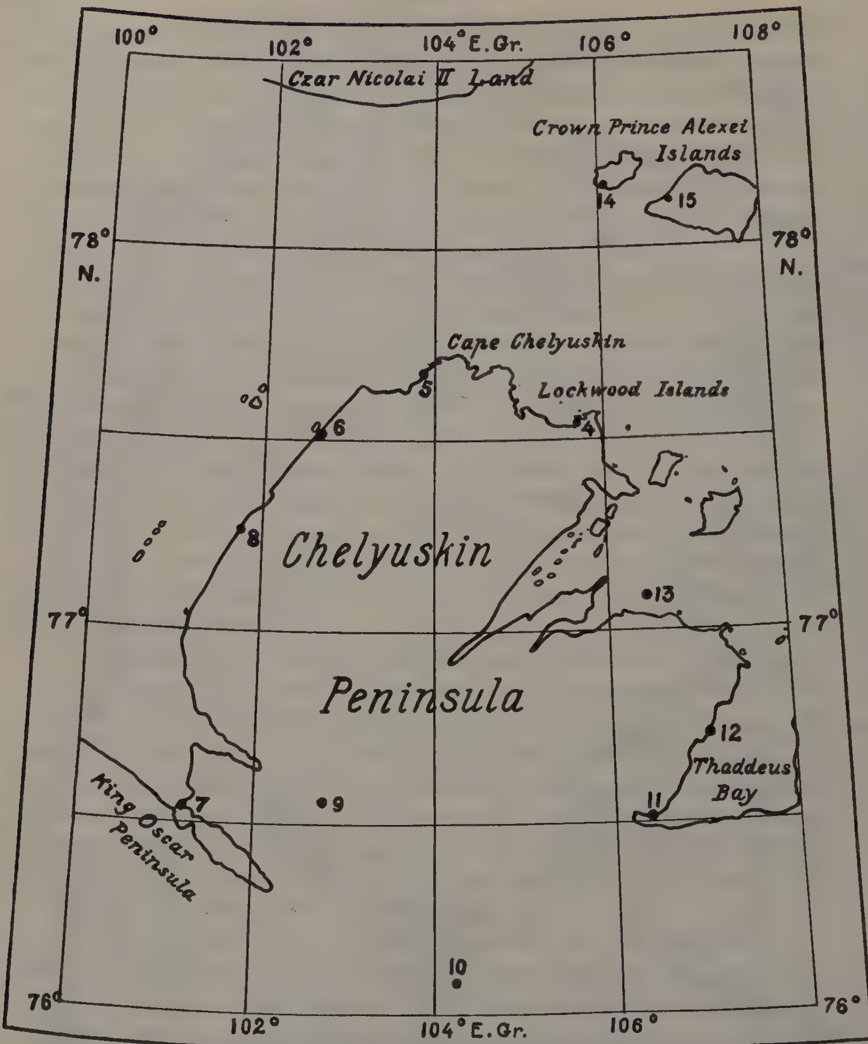


FIG. 2.—Map showing Distribution of Magnetic Stations Nos. 4 to 15 on Chelyuskin Peninsula.

the *Maud*, which was especially built for this expedition, freeze in there, and then let the vessel be carried by the drifting ice across the polar sea until it was released from the grip of the ice between Spitzbergen and Greenland, where the vast ice-masses from the Arctic are drifting slowly south to the Atlantic Ocean. The main object of the Expedition was to study the physical conditions of the Arctic Ocean, but along with the oceanographical work a number of

other observations of interest to geophysics were to be carried out; these included, among others, meteorological, aerological, and magnetic observations. Most of the observations were intrusted to Dr. Sverdrup, but Captain Amundsen himself was to take care of the magnetic observations.

The *Maud* left Vardö, Norway, on July 18, 1918. Ice was met a few days after, but the ice did not form any obstacle worth mentioning before the Jugor Strait, forming the southern entrance to the Kara Sea, was reached. The Strait was filled up with ice, and the *Maud* had to stay at the western entrance until August 17. During this stay two magnetic stations were occupied, one on Vaigach Island at the north side of the Strait, and one at the small Russian trading-place, Khabarowa, at the south side. The last-mentioned station is the one which was occupied by Scott-Hansen on Fridtjof Nansen's north-polar expedition in 1893.

After going through Jugor Strait, the *Maud* met with heavy ice in the Kara Sea and was delayed so much that Dickson Island, north of the Yenisei River, was not reached until August 31. A supply of crude oil was taken on board here, and during this work magnetic observations were carried out. As a steamer with supplies for the wireless station on Dickson Island was expected daily, copies of the magnetic observations were left there, to be sent to the Director of the Department of Terrestrial Magnetism. They were received on January 2, 1919, and the results are published in Volume IV of the "Researches of the Department of Terrestrial Magnetism". (The results are also included in Table 1 of this summary.)

The *Maud* left Dickson Island on September 4, 1918, but again encountered great ice-masses on September 6, west of Nordenskiöld Archipelago. The *Maud* succeeded, however, in passing through the Archipelago, in rounding Cape Chelyuskin, the north point of the continent, and in proceeding about 25 miles further east, but here the progress of the vessel was absolutely stopped by the ice on September 13. There was no harbor, so the *Maud* had to anchor in an open bay about 200 meters from the shore-line. New ice formed rapidly. The *Maud* was frozen fast in a few days, and preparations for the winter had to be made. Although this meant a prolongation of the Expedition for at least one year, it was generally greeted with enthusiasm because wintering here afforded opportunity to carry out a number of investigations in a place hardly touched by former expeditions.

Captain Amundsen selected at once a place for a magnetic observatory close to the shore-line under a small hill. The building was started about September 20, and October 1, it was so far ready that the first observations could be taken in it.

As stated above, it was Captain Amundsen's intention to take the magnetic observations himself, but on September 30, when the magnetic observatory was ready for use, he had the misfortune to fall and break his right arm close to the shoulder. The magnetic

observations up to the end of November were made, therefore, by Dr. Sverdrup, at which time Captain Amundsen was able to take over a part and, later, all of them.

It may be mentioned that systematic observations of the *northern lights* were not carried out because there was no regular night watch. Every display of northern lights between 8 A. M. and 10 P. M. was, however, noted. Only a few photographs of the aurora were taken, mostly as experiments, because it was necessary to save the plates for more northern regions. It may also be mentioned that attempts were made to measure the *potential gradient of the atmospheric-electric field and the conductivity of the air*, but the equipment secured during the war was not satisfactory, the main reason being that satisfactory insulation could not be maintained. The atmospheric-electric observations, therefore, had to be given up.

During April and May, 1919, a number of journeys with dog sledges were planned in order to explore the most northerly peninsula of the continent. Messrs. Hanssen and Wisting were to undertake the longest trips, and they, therefore, received during February and March, instructions from Dr. Sverdrup in taking magnetic observations with the dip circle. Mr. Wisting especially showed himself an able observer, and he was for that reason intrusted with carrying out the magnetic observations on the sledge journeys.

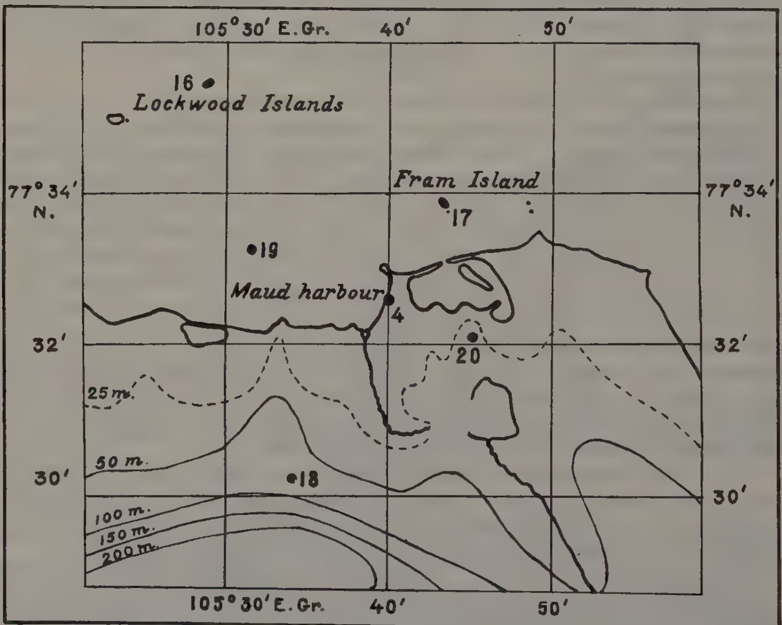


FIG. 3.—Map showing Distribution of Magnetic Stations Nos. 16 to 20 in the Vicinity of Winter-Quarters during 1918 to 1919.

CAPTAIN AMUNDSEN'S ARCTIC SHIP, THE "MAUD."

[Dimensions: Length over all, 120 feet; Beam, 40 feet; Mean Draft, about 15 feet; Registered Tonnage, 297; Machinery, Crude Oil Motor, 240 H. P.; Rig, Three-Masted Schooner.]

1. Captain Amundsen observing with Magnetometer.

2. Winter-Quarters During 1918 to 1919.

Messrs. Hanssen and Wisting were out on two sledge journeys. On the first they were away 23 days, following the coast west and southward for about 150 statute miles and returning the same way. On the second they at first followed their old route, but then crossed overland from the west to the east coast of the peninsula and came back on the 26th day after a round trip of 352 statute miles. Mr. Wisting had then observed at nine stations along the coast or inland, the average distance between the stations being about 45 miles. The observations obtained from the journey in April were taken under very trying conditions, as they had to be carried out in the open air at low temperatures, a snow wall affording the only protection against the wind. Unfortunately the observations comprise only inclination and total intensity and not declination, because neither Mr. Wisting nor Mr. Hanssen was sufficiently familiar with the necessary astronomical observations.

At the end of April a party of four was sent to Crown Prince Alexei Islands lying 40 miles north of the *Maud's* winter quarters. They observed the inclination at two stations with dip circle, No. 154.

Early in the spring of 1919 Captain Amundsen resolved to send home all observations from the first wintering by way of Dickson Island. He hoped that the ice conditions would permit him to start the drift in 1919, and thought it would be best to let two men bring the results of the year's work to civilization as soon as possible, mainly because the observations might get lost if the *Maud* were crushed in the ice. For that reason, in the middle of August, all observations were packed and sewed up in oil cloth. One of the packages containing all original magnetic observations and registrations, information necessary for the computations, maps, and sketches was addressed to the Director of the Department of Terrestrial Magnetism. A notebook was kept on board in which all the magnetic observations were copied. The observations were condensed as much as possible in order to have them all gathered in a small book of practically no weight which might easily be taken along in case the ship had to be abandoned. No copies were made of the registrations, and no attempt had been made to tabulate hourly values from them.

After a hard struggle against the ice, the *Maud* was able to leave the first winter-quarters on September 12, 1919. The two men, Messrs. Tessem and Knudsen, who were going to take the observations back, were left behind. They had built a house on shore, and were equipped with tent, sledge, 5 dogs, provisions and fuel for about one year, rifles, ammunition, maps of the coast, compasses, watch, and theodolite. They were instructed to start, if possible, for Dickson Island in the fall as soon as the ice was trustworthy, but if in their own judgment it was not advisable to go during the fall, then to wait until the next spring. Between Cape Chelyuskin and Dickson Island were three caches with supplies of provisions and fuel laid out in 1915, and the greatest

distance between two caches was only 250 miles. The plan seemed perfectly safe, and, in addition, both men had had considerable experience in arctic traveling and were good hunters. However, since leaving Messrs. Tessem and Knudsen on September 12, 1919, nothing has been heard from them. A searching expedition, sent out in 1920, has not brought final result as to their fate, but it cannot be doubted that they perished. The original copies of the absolute observations and all the original photographic registrations of declination were lost with them. *No copies exist of the photographic registrations, and so they are a total loss, but all absolute observations had been copied.*

It soon became apparent that it would not have been necessary to send Messrs. Tessem and Knudsen home because the *Maud* did not succeed in penetrating into the drifting ice of the polar sea, as hoped. In the vicinity of Cape Chelyuskin and across the Nordenskiöld Sea, the *Maud* met much more ice than earlier expeditions have encountered in the same season, and on the east side of the New Siberian Islands there was only a narrow lead of open water between the heavy pack-ice and the coast. An attempt to penetrate to the north here soon had to be given up, and under these conditions nothing was left but to seek new winter-quarters at the coast. Captain Amundsen resolved to go to Chaun Bay, but when Ayon Island was reached at the entrance of the bay, further progress was absolutely stopped by the ice. A strip of old ice 2 miles broad was found along the coast. The *Maud* was forced in some hundred yards among the old ice-floes, where she stayed perfectly safe during the whole winter.

When the Expedition came to Ayon Island, a number of natives of the Chukchi tribe were living there. These natives were reindeer nomads who spent the winter in the timbered inland, but the summer at the coast. It soon became apparent that they were so primitive, that it would be of interest to learn as much as possible about their customs. For that reason, at Captain Amundsen's suggestion, Dr. Sverdrup went with the natives when they left the the coast and stayed among them for 7½ months until they came back to the coast the following spring. Besides making notes of ethnological interest, Dr. Sverdrup carried out magnetic observations in the inland, using theodolite-magnetometer No. 8, with tripod, Dover dip circle, No. 154, a small astronomical theodolite (Hildebrandt, Freiberg, No. 4474), and an observing tent. The time before the departure was so short and so much had to be done to provide for the different observations which were to be taken on board during the winter, that no time was left for magnetic observations.

It was rather trying to travel with the natives because they moved so slowly. They took two months to cover the 170 miles from the coast to the inland where they stayed during the winter. On the days when they were moving, most of the time till noon was used for preparations, for taking down the tent, lashing the

sledges and catching the reindeer, and then they were able to cover 8 to 10 miles, but generally much less. It often happened, after having spent hours and hours in getting ready, they stopped after the first mile.

In this season conditions were very unfavorable for observations. The daylight was short, and much bad weather made astronomical observations impossible. Observations were made, therefore, at only one station, but no astronomical observations could be secured. From the end of December, 1919, to the beginning of March, 1920, the natives were living in the same place, and magnetic observations were usually secured once a week, but the low temperature in the observing tent sometimes was a hindrance. The observations with the dip circle once had to be interrupted because frost formed so rapidly on the agate bearings for the dip needle that the movement of the needle was not free a moment after it was placed on the agate planes.

At the end of March, 1920, a number of natives were going to the yearly market at the Russian settlement, Panteleika, close to the Kolyma River, to exchange their furs for tobacco and tea. The distance was about 100 miles, and most of the natives did not travel with all their belongings as they did when they moved with their reindeer herd, but they only used their small personal sledges drawn by two reindeer, by means of which they were able to cover the distance in two to three days. Dr. Sverdrup was anxious to go with them, partly in order to see the Russian settlement and partly in order to extend the magnetic observations as far west as possible, but it was difficult to transport the instruments under the circumstances. After some trouble a sledge with two deer was obtained for the instruments, but it was necessary to leave the trunk-cases behind to reduce the weight. The settlement was reached without mishap, and two series of magnetic observations were taken there.

On the way back the reindeer which were pulling the sledge with the instruments were worn out and on the verge of breaking down. A stop was made at a Chukchi tent halfway between Panteleika and the winter station to wait for families who came with tents and all belongings to join the group with which Dr. Sverdrup stayed. The interruption was utilized for magnetic and astronomical observations. The Chukchi group now on the way back to the coast was rejoined by the end of April. Two more stations were then occupied. The conditions were now very favorable for observations; there was continuous daylight and very often brilliant sunshine during the day, the temperature in the tent rising several degrees above the freezing point. Dr. Sverdrup left the natives on May 15, 1920, and traveling by dog sledge, reached the *Maud* on May 17. Magnetic and astronomical observations had been made at 5 stations at an average distance apart of about 50 miles. A station on Ayon Island was occupied in the middle of June.

During Dr. Sverdrup's absence, Mr. Wisting had taken several

observations with dip circle No. 205 on the ice a short distance from the *Maud*. On December 1, 1919, Messrs. Hanssen and Wisting left the vessel with two dog teams. Their instructions were to reach the nearest wireless station either at Nome or Anadyr, to send information about the Expedition, and to secure new equipment of different kinds to be sent to Nome, where Captain Amundsen had decided to call in July, 1920. Among the telegrams which were to be sent was one to the Director of the Department of Terrestrial Magnetism in which Captain Amundsen asked for two pairs of intensity needles for dip circle No. 205, because one pair seemed to have been damaged in some way during the inevitably rough transportation on the sledge journeys at Cape Chelyuskin. Mr. Wisting was also instructed to carry out on this journey magnetic observations along the coast with dip circle No. 205, and to occupy stations at an average distance apart of about 50 miles. The traveling along the coast in the middle of the winter was extremely hard, and Mr. Wisting had the same experience Dr. Sverdrup had, viz., the conditions were very unfavorable for carrying out magnetic observations while traveling in this season. Messrs. Wisting and Hanssen reached Cape Deschnew (East Cape) at the Bering Strait early in February. From here Mr. Hanssen proceeded alone to Anadyr, where, through the courtesy of the Russian officials and officials in the United States, he succeeded in sending the telegrams, including the one to the Director of the Department of Terrestrial Magnetism, who received it on March 29, 1920. In the meantime Mr. Wisting stayed with a trader living in the native village of Kain-ge-skon, at the south entrance to Bering Strait. At this point he took a number of magnetic observations in a snow hut, which he built for that purpose. Mr. Hanssen returned from Anadyr in the middle of May, and together they covered the 700 miles from the Bering Strait to the *Maud* in 28 days. During the last 14 days, traveling was very difficult because the snow had melted on the land and they had to keep on the solid sea-ice. At the mouths of the numerous rivers the sea-ice was often covered with fresh water to a distance of several miles from the shore, and they had to make great detours to avoid the water. In some places it could not be avoided, and they were forced to walk miles in water almost kneedeep. In spite of the short time and the hardships connected with fast traveling, Mr. Wisting carried out his instructions completely. He observed at 11 stations along the coast, the average distance between them being about 60 miles, and he brought the instrument back in perfect condition. However, his observations were, as before, restricted to inclination and total intensity.

The *Maud* left Ayon Island on July 6 and anchored at Nome on July 27, 1920. Here the Expedition learned that no news had been received in Norway about Messrs. Tessem and Knudsen. The copy of the magnetic observations for the winter 1918-1919, together with all original observations for the winter 1919-1920, and

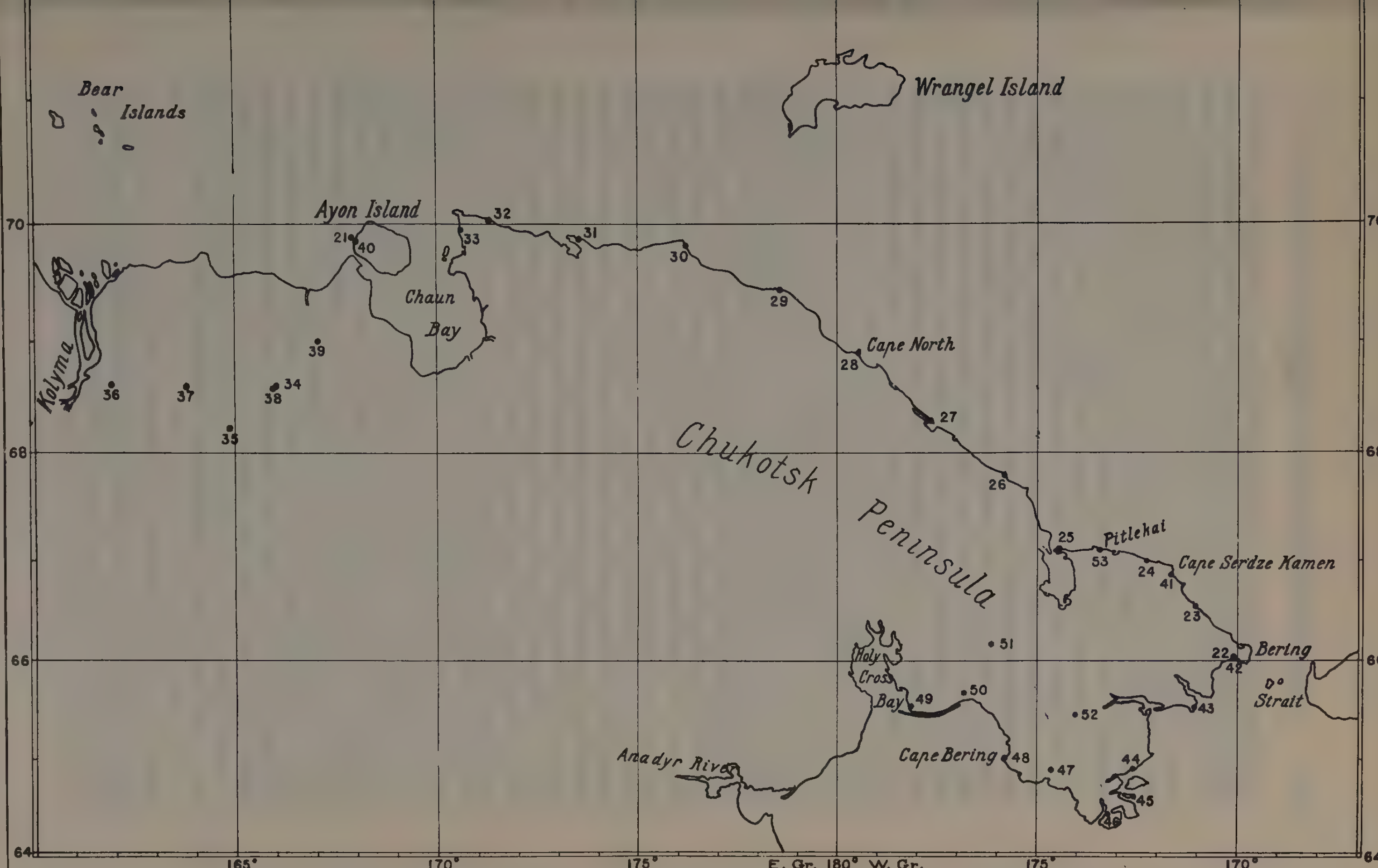


FIG. 4.—Map showing Distribution of Magnetic Stations Nos. 21 to 53 in Northeastern Siberia.
[NOTE: Station No. 28 should be plotted in longitude 179° 29′ E instead of 179° 29′ W.]

copies of astronomical and meteorological observations as far as they were of importance for the computations, were, therefore, sent to the Director of the Department of Terrestrial Magnetism, who received them on September 22, 1920. While at Nome, a package was received from the Department of Terrestrial Magnetism containing two pairs of intensity needles for dip circle No. 205, according to Captain Amundsen's wireless request from Anadyr.

After a short stay, the *Maud* again left for the Arctic on August 8, to make a third attempt to penetrate to the large drifting ice-fields in the north. The attempt failed once more. Even in Bering Strait heavy ice was encountered and it was only with great difficulty that Cape Serdze Kamen, 70 miles west of the Strait, was reached. Further progress was absolutely impossible and accordingly winter quarters for 1920-1921 were established at Cape Serdze Kamen. In the last struggle against the ice the propeller was broken and the shaft was damaged. It was necessary to proceed in the following summer (1921) to Seattle for repairs to the vessel.

Before departing from Nome, the personnel of the Expedition was reduced to four, four having left at Nome because the Expedition would last several years more than anyone thought when the start was made in 1918. This had, of course, an influence upon the scientific work, which also was hampered by the severe weather conditions during the first part of the winter. The ice broke up close to the shore several times in October and November, and it was not before the end of November that the *Maud* was frozen fast. At the end of November a snow hut, where a few observations were made, was built on the shore north of the vessel. Captain Amundsen himself acted as cook and was for that reason prevented from observing. During a severe fourteen-days' snowstorm in the first part of December, the snow hut was buried by the drifting snow and the roof was broken down. Fortunately the instruments had been removed as soon as the storm started. During January, 1921, a number of observations were taken in an observing tent which was set up on a low mound close to the shore west of the *Maud*.

On January 31 Dr. Sverdrup and Mr. Wisting left the *Maud* with two dog teams to follow the coast to Holy Cross Bay, if possible to Anadyr, and on the return to cross overland from Holy Cross to Kolutchin Bay. The objects were to take magnetic observations and to collect information of ethnological interest. The instrumental outfit consisted of dip circle No. 205, theodolite No. 4474, and two watches. The coast followed has a very bad reputation among the traders and the natives, on account of the numerous blizzards; the east and south coasts of the Chukotsk Peninsula are in this respect much worse than the north coast.

The party was away from the *Maud* 69 days and covered 1,200 miles, but on 23 of the days could not proceed on account of blizzards. The attempt to cross overland from Holy Cross Bay to Kolutchin Bay failed. The snow was so deep and soft that the daily travel was very small, and the party had to turn back because

dog feed got scarce. During February and March magnetic observations were made at 11 stations, but on account of the bad weather astronomical observations could be secured at only a few of the stations.

After the return, Dr. Sverdrup took a short trip to Pitlekai, a native village about 50 miles west of the winter quarters, where A. E. Nordenskiöld had taken magnetic observations during the *Vega's* wintering in 1878-1879. A wooden pole driven down in the ground had marked the place of his observations, but according to the natives nothing was now left of this pole. An old woman, who remembered the *Vega*, however, indicated the approximate place where Nordenskiöld's ice-house had stood, and the tent was set up there and a series of observations was taken with dip circle No. 205. The magnetic observations of this winter were closed on April 26, 1921, by simultaneous observations with magnetometer No. 8, and dip circle No. 205, at the station occupied in January, 1921.

The *Maud* left her winter quarters on July 1, and reached Seattle on August 31. It is Captain Amundsen's intention to start out again in 1922 and try once more to get into the drifting ice. The *Maud*, therefore, is being overhauled in Seattle and equipped again for a number of years. During these repairs Dr. Sverdrup took the magnetometer and the two dip circles to Washington where they were compared with the standards of the Department of Terrestrial Magnetism. Dr. Sverdrup reported at Washington in the latter part of October, 1921, and continued there until March, 1922.

(In the summer of 1921, Captain Jacobsen searched the coast northeast of Port Dickson and returned to Norway by way of Petrograd in February, 1922. At Cape Wild, about 250 miles northeast of Port Dickson, where a cache had been left by the "Eclipse" Expedition in 1915, a letter dated November 14, 1919, and signed by Tessem and Knudsen, was found. In this letter was stated that they had arrived in good health at Cape Wild on November 10, 1919, but had found the cache there partly damaged by sea-water, because the waves had, apparently, washed over the point on which the cache was placed. They had moved part of the cache about 25 yards in and had supplemented their own provisions. With supplies for 20 days they proceeded to Port Dickson. On the coast between Cape Wild and Port Dickson, Captain Jacobsen found remnants of several campfires built of driftwood. At the last one, pieces of half-burnt clothing, buttons, and cartridges and other things were found. It has been suggested that one of the two men had died and that his body was burned by his companion, of whom, however, no trace has been found.)

DESCRIPTIONS OF STATIONS.

In general the topography of the regions in the neighborhood of the stations, the absence of prominent marks and buildings, and the

meteorological conditions prevailing made infeasible detailed descriptions such as would permit precise recovery of all the points. Such descriptions as were possible to give will be found in the fuller publication. Any one requiring information regarding location of any station, before the fuller publication appears, should apply to the Director of the Department of Terrestrial Magnetism, Washington, D. C.

SECULAR-VARIATION DATA.

Previous observations of the magnetic elements in the general region covered by the Expedition were made by A. E. Nordenskiöld on the "Vega Expedition", during 1878–79, and by Nansen during the "Norwegian North Polar Expedition" of 1893–96. Table 2 shows the data obtained for the several magnetic elements by previous observers and by the "Maud Expedition", together with the resulting values for mean annual change. It had been hoped also to obtain annual-change values at Cape Chelyuskin, but Nordenskiöld's station at this place was apparently in a locally disturbed area, his value for declination being 129° 09′ east; it was not feasible, therefore, to get any reliable secular-change data by comparing his results with values interpolated for his position from stations occupied on the "Maud Expedition". The data for the "Maud Expedition" values at St. Laurent Bay and Konyam Bay are obtained by interpolation for the first case from values at stations Nos. 42 and 43, and in the second case from values at stations Nos. 44 and 45.

TABLE 2.—*Secular-Variation Data.*

Station	Latitude	Long. East of Gr.	Authority	Date	Declination Value	Declination Annual Change	Inclination Value	Inclination Annual Change	Hor. Int. Value	Hor. Int. Ann Cha
	° ′	° ′			° ′	′	° ′	′	c.g.s.	c.g
Port Dickson	73 30 N	80 26	Nordenskiöld	Aug 1878	26 25 E	....	82 55 N	....	.08007	....
			Amundsen	Sep 1918	28 43 E	3.4 E	82 38 N	0.4 S	.07503	—.0
Khabarowa	69 40 N	60 24	Nordenskiöld	Jul 1878	17 07 E	....	....	....	.11558	....
			Nansen	Aug 1893	....	....	77 38 N	....	.11448	—.0
			Amundsen	Aug 1918	19 54 E	4.2 E	78 37 N	2.4 N	.10920	—.0
Pitlekai	67 06 N	186 29	Nordenskiöld	Mar 1879	19 42 E	....	77 01 N	....	.13188	....
			Amundsen	Apr 1921	15 03 E	6.6 W	76 26 N	0.8 S	.13213	+.0
St. Laurent Bay	65 35 N	189 16	Nordenskiöld	Jul 1879	20 24 E	....	75 55 N	....	.14178	....
			Amundsen	Feb 1921	....	....	75 16 N	0.9 S	.14210	+.0
Konyam Bay	64 50 N	187 03	Nordenskiöld	Jul 1879	17 52 E	....	75 10 N	....	.14725	....
			Amundsen	Feb 1921	....	....	74 32 N	0.9 S	.14810	+.0

PERIODICITY OF ACTIVITY IN TERRESTRIAL MAGNETISM AND THE ROTATION OF THE SUN.[1]

By Dr. G. Angenheister.

The methods by which researches into the physical causes of magnetic storms have been made are essentially as follows:

(I) It has been attempted to determine the geographic distribution of magnetic storms over the Earth. In this way the influence of the Earth's permanent magnetic field, on the geographic arrangement of the disturbance field, has been recognized, and it was made probable that there is an extra-terrestrial cause of disturbance, solar radiation, acting upon this permanent field. We have learned to distinguish several different properties of these storms, such as that some of them are chiefly local in their character, whereas others range over the whole Earth. The known pulsations also belong to the latter.

(II) It has also been sought to determine the velocity of the propagations of disturbances in terrestrial magnetism over the Earth. I believe that, at any rate for the known pulsations, the time-intervals between occurrence of the variations at different stations are smaller than the limits of accuracy attainable with our present means of measurement; certainly they are smaller than 0.1 min. for 10,000 km.

(III) It has been sought to discover a periodicity in these storms by study of their recurrence. There is no doubt that periods of one day, one year, and eleven years have been discovered, which show clearly that the Sun has its influence upon them as a source of disturbance. This is confirmed by a period of the same duration as that of the Sun's rotation.

(IV) It has also been sought to trace the connection between observed phenomena on the Sun and observed occurrences in terrestrial magnetism—to distinguish certain sun-spots as origins of storms. By taking the period between the passage of a given sun-spot across the central meridian and the outbreak of a storm, the velocity of the disturbance in interplanetary space has been computed. Up to the present, this has not been successful. Solar phenomena cannot be identified with disturbances in terrestrial magnetism with certainty sufficient to construct a theory of their relation to one another.

The only success that can be claimed apparently is that the well-known periods in the solar phenomena, such as the eleven-year period, and the rotation have been found in the records of terrestrial magnetism. Still it is hardly possible to regard one as a

[1] Translated by Mr. C. J. Westland, to whom the author expresses his grateful obligations.

function of the other, certainly not with regard to the period of the approximate duration of the Sun's rotation.

It is also noticeable that the data concerning magnetic storms which are supposed to agree with the period of solar rotation appear to vary over wide limits, from about 25 to 30 days. It seems, therefore, not improbable from the preliminary view, that we have to consider the overlapping of several periods connected more or less closely with one another.

In a previous research, I have demonstrated the existence of a 26½-day period in magnetic activity and in the areas of spots and flocculi upon the Sun. A relationship of the two periods to one another in the sense of cause and effect was altogether impossible. It was shown also that at the time of maximum magnetic activity the thickly spotted hemisphere was turned toward us in 1911, while in 1915 the more thinly spotted hemisphere was turned away from us. Beside this 26½-day period there seems to be another of approximately 30 days, especially with respect to the repetition of the greater storms.

In the following, I shall deal at first with some difficulties which we have before us, if we suggest that some of the solar phenomena correspond with the events observed in terrestrial magnetism. We must, in fact, consider that upon the Sun there are certainly various layers which move with different velocities, and in addition to this the rotation period of each layer varies with the latitude. Thus, I shall endeavor to show that in addition to the 26½-day period there is a 30-day period of greater disturbance, and with regard to these I shall show that there is a probable connection with the solar activity which tends to reconcile the contradictory data concerning the 26½-day period in the years 1911 and 1915 stated above.

(A) IS THE VELOCITY OF THE SUN'S ROTATION VARIABLE WITH TIME?

Our knowledge of the Sun's rotation has been obtained from observation of the spots, faculæ, and prominences, which move with the rotation of the earthward side of the Sun, and sometimes last through several rotations. We have additional evidence in the spectroscopic observations of both limbs of the Sun, one advancing and the other receding, in which the comparison of spectra with one another shows the displacement of the lines according to the Doppler effect, from which the velocity of rotation can be determined. Both these methods give approximately the same

results, viz, a synodic period of about 26½ days for heliocentric latitude, 0°, about 28 days for 30°, and about 32 days for 60°. The observations of both methods, however, show discrepancies among themselves, which become greater in accordance with the errors of observation. This is not surprising in observations of spots, faculæ and prominences, as these features undoubtedly have proper motions in longitude and latitude, which tend to give erroneous values of the velocity of rotation. The spectroscopic observations of the Sun's limbs show discrepancies of 12 per cent for the same heliocentric latitude; for example, the equatorial velocity is found to be from 1.86 to 2.11 kilometers per second, and these are less easy to explain. H. H. Plaskett, writing in the *Astrophysical Journal* (1916, p. 145) believes that these varying results really exist. Thus the Sun must have a variable velocity of rotation, which has fallen 5 per cent (from 2.05 km. per second to 1.95 km. per second) during the years 1906 to 1915. The synodic rotation must have lengthened its period from 26½ to 28 days in this time. Again the period must have been ½ day longer in 1915 than in 1913. And yet again the velocity of rotation must have developed a short-period variation of about 7 per cent amplitude (0.15 km. per second) in June and July, 1915. On the contrary, De Lury does not consider these surprising results to be real (*Astrophysical Journal*, 1916, p. 177). His theory is that layers of vapor and dust between the observer and the Sun affect the spectra of the Sun's limbs, so that the observed variation of the displaced lines with time is merely the result of varying amount of dust situated either in the atmosphere of the Sun or in that of the Earth, or possibly in space between them. The light which is emitted from the whole body of the Sun falls on this dust. Then the spectrum of this dust becomes superposed upon that of the Sun's limb, making it more like that of the middle of the disc, and thus it obliterates the displacement of the lines caused by the rotation. Hence the dust seems to diminish the velocity of rotation, which is proportional to the displacement. On days which were free from dust and vapor, he found $v=1.97$ km. per second; on moist days it was 1.82 km. per second. A moisture of this description would, of course, have considerable effect upon the determination of the solar constant. The measurements of the solar constant must tend to become as free as possible from the errors due to moisture in the atmosphere, by their comparison with one another, and by the choice of stations in localities which are

especially free from moisture. Obviously, they cannot be cleared of the influence of any conditions of moisture in the atmosphere of the Sun or in interplanetary space. If the vapor which causes the magnetic variation of velocity of solar rotation comes from solar activity, a connection between this velocity and the solar activity should be found as the result thereof.

A scale for the solar activity can be found in the relative numbers of sun-spots *R*, in the magnetic character numbers *Ch*, and the value of the solar constant *S*.

Year	V (km.)	U (days)	S (Abbot) (gr. cal. min.)	R	Ch	S (Bigelow)
1906	2.05	26.2	1.956	63	0.646	3.975
1913	1.99	27.1	1.915	1	0.485	4.003
1915	1.95	27.8	1.950	46	0.620	3.990

R and *Ch* show parallel courses. A diagram was drawn showing these in comparison with the velocity of rotation *V*, and the duration of the rotation *U* at the equator; this diagram does not seem to show any such parallelism in the rotation and solar activity. *S* according to Abbot and *S* according to Bigelow run in contrary directions. I have also compared the periodic fluctuation of the velocity of rotation observed in June and July, 1915, with the solar activity derived from the magnetic character numbers. Here a connection seems more probable.

Thus, if at the time of increased solar activity and increased magnetic activity resulting therefrom, the space between Sun and Earth were full of vapor the spectroscopic measurements would suggest a decrease of velocity of rotation, not really existing. The vapor may consist of the Sun's dust, small drops, or swarms of electrons, but the diagram mentioned does not show a sufficiently close coincidence to permit the question to be regarded as decided.

(B) IS THE VELOCITY OF THE SUN'S ROTATION VARIABLE WITH THE HEIGHT OF THE SUN'S ATMOSPHERE?

St. John and Adams, by spectroscopic observations, find different velocities of rotation for different heights of the solar atmosphere. The following table shows the velocities in longitude per day for latitudes 7° and 38°, derived from their measurements of the highest layer of the K_3 line, for the lower layer of the aqueous matter and the comparatively low reversing layer. I have added

the corresponding synodic rotation in days. The velocities stated above then become as follows:

	Sun's Latitude			
	Velocity of Rotation		Duration of Rotation	
	7°	38°	7°	38°
	°	°	days	days
K_3	15.5	15.4	24.7	24.9
H	15.1	14.3	25.5	26.9
Reversing Layer	14.4	13.2	26.7	29.2

De Lury believes that this result may also be rendered fallacious by a superposed spectrum of dust or vapor. On days free from moisture he finds connection between the velocity of rotation and height of atmosphere, but he finds it well marked on damp days. A revision of the results of observation in 1909-1913 leads him to the opposite conclusion which reduces the velocity stated above.

Briefly, it may be stated with reference to the duration of the Sun's rotation: (1) That the spectroscopic measurements themselves show results varying about one or two days for the equator; (2) That it is not certainly decided whether these are real, and (3) that it is also uncertain whether the velocity of rotation varies with the height. Thus it will be difficult to state that any value of the duration of the Sun's rotation, derived from the repetition of magnetic storms, may correspond to any given heliocentric latitude or any given height, wherein we, therefore, should locate the cause of the storm.

(c) TERRESTRIAL MAGNETISM AND SOLAR ROTATION

Adolf Schmidt (*Meteor. Zeitsch.*, 1909) showed that very great magnetic storms are repeated after certain intervals, of which the average value is in round numbers 30 days. Five out of seven of the greatest storms between 1890 and 1909 follow this law. From this it would appear that a definite part of the Sun's surface rotates once in 30 days, and sets in motion new magnetic storms from time to time, frequently after long pauses. All these five storms took place at the time of spot maximum, viz., Oct. 31, 1893; July 20, 1894; Aug. 20, 1894; Feb. 9, 1907, and Sept. 25, 1909 (*Meteor. Zeitsch.*, 1909, p. 509). Adolf Schmidt has recently shown in the Potsdam Annual Report of 1910-11-12-13, repetitions of storms in a single year at intervals of 27½ days.

Other observers find other periods for the return of storms:

Hornstein and Liznar..........	25.87 days	
Maunder (Greenwich).........	27.275 "	(magnetic storms)
Harvey (Toronto).............	27.246 "	
Birkeland (Polar expeditions)...	29.1	
Chree (Kew).................	27-28	(magnetic character numbers)

These discrepancies in the periods are partly explainable, if we accept the view that spots or faculæ are the causes of the storms, because in the first place spots and faculæ have a proper motion on the Sun's surface which may either delay or accelerate their recurrence in the same position of the Earth, so that a uniform period can hardly be expected; and in the second place, they are situated in different latitudes and have the corresponding differences of rotation-period.

The spots are situated chiefly between latitudes 10° and 35°, the faculæ are also to be found in higher latitudes. Moreover, by taking the mean of longer intervals, we get no constant value for the mean latitude of both spots and faculæ. On the contrary, in the eleven-year period, the mean latitude of the spots moves from 35° at minimum to 10° at minimum, that is, toward the equator, and then at the beginning of the new period, it begins again in 35°. The faculæ, on the other hand, move toward the pole in the same period. Thus, if spots or faculæ are the causes of storms, the repetitions of these storms must give a variable period.

Another cause of uncertainty is introduced into the problem of a definite period, if the Sun's rotation is also variable with time for the same latitude and a stated level, as indicated by the spectroscopic measurements by Plaskett, quoted above.

Many of the observed variations in the time-length of period may be explained in this way. But it will be hardly possible to attribute the 30-day period of the storms, found by Birkeland and Adolf Schmidt, to a similar period of the spots and faculæ. The spots show a synodic revolution of about 26.7 days (at the equator) to 28.0 days (in lat. 30°). Faculæ and calcium flocculi give nearly the same or slightly shorter periods. Thus, if a 30-day period is to be sought, we must have recourse to spots or faculæ which are situated in heliocentric latitude 50°, where they are never, or at least very rarely, seen. Also the cone of rays would require a very wide angle if rays of light emerging in straight lines were to reach the Earth. If we seek the origin of the storms in the zones where the spots and faculæ are situated, i. e., in latitudes 10° to 30°, which has been the usual procedure, then the causes of these storms which repeat

themselves with a 30-day interval can never be situated on the layer where spots and faculæ are formed, because there the rotation-period is too short. If the measurements made by St. John and Adams are reliable in showing the increase of angular velocity of rotation with the height, then the causes of the storms cannot be higher but must be deeper than the spot-layer—deeper than the reversing layer. We should have then the strange physical appearance of a solar atmosphere rotating more rapidly than the nucleus of the Sun. Thus, we must either locate the seat of disturbance at a depth hitherto not investigated, in which layer we accept a duration of rotation previously not observed in these latitudes (10° to 30°); or, as an alternative, we must place the seat of disturbance in those zones of latitude where the required value of 29 to 30 days has been recorded, but where spots and faculæ are seldom to be seen. Moreover, a very wide angle of the cone of rays proceeding in straight lines must be supposed, if the Earth is to intercept such rays.

(D) THE REPETITION OF MAGNETIC STORMS AFTER COMPLETION OF ONE SOLAR ROTATION.

The great discrepancies in the length of the period between the various observed repetitions of the storms encourages the belief that perhaps there are various types of storms which have been utilized in computing the period. Thus there may be: (1) Very great storms of which the sources are situated very deep in the solar atmosphere, and which continue to be active for many years. A duration of rotation amounting to 30 days must be ascribed to this depth of the Sun, and possibly the rotation-period may be constant for this layer in all latitudes of the Sun. (2) Smaller storms which have their sources less deeply situated, possibly just in the reversing layer, and which in such movable material could only maintain a constant duration of rotation for one actual revolution.

This layer has a period of about 26 or 28 days, varying with the latitude. From this point of view, which can be regarded only as a working hypothesis, all the material of the magnetic observations during the years 1906 to 1918, and especially the time of minimum activity 1910 to 1914, was made use of. The international character numbers were found very useful, and also the magnetic observations from tropical stations, especially Batavia, Samoa, and Porto Rico, because of the greater simplicity of the storms in the tropics near the magnetic equator.

(E) THE GREAT STORMS.

From the years of great disturbance—1909-1914—for the present only international character numbers 1.8 to 2.0 were selected from the yearly report. The two great storms which occurred close together on September 25 and 30, 1909, were taken as *initium a quo*. The storm of Sept. 25, 1909, is far the greatest yet observed; it is the last of the five storms in which Adolf Schmidt demonstrated the return after *n* times 30 days. All seventeen storms of character 1.8–2.0, collected from the years 1910-1914, appear then to be repetitions of the two storms of Sept. 25 and 30, 1909, if a period of rotation of 30.0 days is adopted. The dates computed for the repetitions of these storms (accepting this period of rotation) are given in Table 1 for comparison with the observed dates.

TABLE 1.

Series A.				Series B.			
Char.	Observed Date	Computed Date	O-C	Char.	Observed Date	Computed Date	O-C
1.8	Sept. 30, 1909	....	.....	2.0	Sept. 25, 1909	....	....
1.9	Mar. 28, 1910	Mar. 29, 1910	—1	1.8	Aug. 22, 1910	Aug. 21, 1910	+1
1.8	Sept. 29, 1910	Sept. 25, 1910	+4	1.9	Mar. 20, 1911	Mar. 19, 1911	+1
1.8	Feb. 21, 1911	Feb. 22, 1911	—1	1.9	Dec. 11, 1911	Dec. 14, 1911	—3
1.8	Aug. 23, 1911	Aug. 21, 1911	+2	1.9	Apr. 9, 1913	Apr. 7, 1913	+2
1.8	Sept. 17, 1912	Sept. 14, 1912	+3	1.8	Jul. 29, 1914	Jul. 31, 1914	—2
1.9	Apr. 6, 1914	Apr. 7, 1914	—1	1.8	Sept. 27, 1914	Sept. 29, 1914	—2
				1.9	Oct. 28, 1914	Oct. 29, 1914	—1

The algebraical mean of the differences: observed—calculated for both series taken together = +0.15 day. It seems from this that in the five years, 1910–1914, two positions upon the Sun have been identified as principal sources of disturbance, and that these have maintained their positions within the Sun unaltered. These are the centers of the disturbances of Sept. 25 and 30, 1909. They lie close beside one another. According to our hypothesis, these centers of disturbance must be considered to be at a depth within the Sun where the duration of rotation amounts to 30 days.

In Table 2 the Series A and B are extended to include several other storms; *n* is used to designate the number of rotations of the Sun of 30 days each—reckoned from the same starting point as the first disturbance. *R* is the period of the rotation computed from two consecutive storms. We extend now our consideration to storms of character 2.0—1.5 during the sun-spot minimum in

1910-1914. If we divide the Sun into two parts, taking a circle of longitude as the boundary line, and keeping the two adjacent storm centers of the series *A* and *B* in the same hemisphere, then this hemisphere supplies 41 out of the 50 storms of character 2.0—1.5. Out of the 37 storms of character 2.0—1.6 during this time, there are 33 from one and 4 from the other half of the Sun.

TABLE 2.

Date	Char.	n	R	Date	Char.	n	R
Jan. 3, 1909	2.0	....	....	Sept. 25, 1909	2.0	....	....
Jan. 31, 1909	1.9	0.93	28.0	Aug. 22, 1910	1.8	11.03	30.1
Sept. 30, 1909	1.8	9.0	30.2	Mar. 20, 1911	1.9	18.03	30.0
Mar. 28, 1910	1.9	14.97	29.8	Dec. 11, 1912	1.9	26.9	29.6
Feb. 21, 1911	1.8	25.93	29.9	Apr. 9, 1913	1.9	43.07	30.3
Aug. 23, 1911	1.8	32.07	30.7	Jul. 29, 1914	1.8	58.93	29.8
Apr. 6, 1914	1.9	63.97	29.9	Sept. 27, 1914	1.8	60.93	30.0
Apr. 25, 1916	1.8	88.97	30.0	Oct. 28, 1914	1.9	61.97	31.0
Dec. 16, 1917	2.0	108.97	29.9	Sept. 23, 1915	1.8	72.97	30.0
				Feb. 15, 1917	1.9	90.00	30.1
		Mean	29.8	Aug. 13, 1917	1.9	95.97	29.8
						Mean	30.1

From what has been written above, there can be little doubt as to the real existence of a 30-day period of the greater magnetic storms which took place during the spot minimum of 1910-1914.

It was necessary to make a closer investigation for the time of maximum. For this purpose, the character numbers from 1906 to 1918 were arranged according to 30-day series, beginning at January 11, 1906. In this way it was determined how the various degrees of character from 0 to 2.0 were distributed on the different days of the rotation, and how this distribution altered from the time of maximum activity to that of the minimum. Then it became noticeable that as a rule, two-thirds of the greater character number of a year of maximum is caused by an increase of storms of character 1.2–2.0. It seemed, therefore, especially advisable to make a separate study of these storms of character 1.2–2.0. Accordingly, the two 30-day series 1906–1918 were divided into two halves, one of which covers the time from the 14th to the 28th day of the rotation. Table 3 gives the number per annum of the 1.2–2.0 storms—at the mean times of the 1906–1909 maximum, of the 1910–1914 minimum, and again of the 1915–1918 maximum. Each half is still further divided into 3 parts of 5 days, so that each gives three numbers.

TABLE 3.—*Yearly average of number of storms of character 1.2—2.0 for a five-day phase interval.*

Rotation Days	A-Half			B-Half			A-Half	B-Half	A-B
	(29–3)	(4–8)	(9–13)	(14–18)	(19–23)	(24–28)			
Max. 1906-1909	6.2	9.0	9.0	7.8	5.2	7.8	24.2	20.8	1.16
Min. 1910-1914	6.8	8.0	8.4	3.6	2.6	3.2	23.2	9.4	2.47
Max. 1915-1918	10.0	11.2	12.5	9.0	12.2	9.2	33.7	30.4	1.11

From the figures in Table 3 we see: (1) that for all three intervals of time the A-half gives a larger number of storms than the B-half; (2) that the differences between the halves are very large at minimum, but at maximum very much less marked; (3) that for the A-half the mean yearly number of storms 1.2 to 2.0 is almost equally large for the maximum of 1906–1909 and for the minimum of 1910–1914, so that in the A-half the eleven-year period is very much less sharply defined than in the B-half.

Perhaps these matters stand out more clearly if, instead of the number n of the storms of character ν, 1.2–2.0, we take for comparison the sum $\sum_{\nu=1.2}^{\nu=2.0} n\,\nu$ for five days of the rotation. If we call days of which the character numbers lie between the limits 1.2–2.0 "*disturbed days*", then the numbers $\sum n\,\nu$ of Table 4 become a unit of measurement for the yearly mean of this amount of disturbance for the five-day phase intervals referred to.

TABLE 4.—*Yearly average of disturbance for a five-day phase interval.*

Rotation Days		A-Half			B-Half			A-Half	B-Half	A-B
		(29–3)	(4–8)	(9–13)	(14–18)	(19–23)	(24–28)			
Max.	1906-1907	61	121	121	*144*	103	83	303	330	....
	1908-1909	121	*152*	139	81	55	*146*	412	282	....
Min.	1910-1911	145	160	*179*	88	42	52	484	182	2.7
	1912-1913	49	*94*	92	20	*40*	33	235	93	2.5
	1914	*109*	51	51	25	12	50	211	87	2.4
Max.	1915-1916	125	159	*171*	122	*188*	136	455	446	....
	1917-1918	180	*189*	173	131	*173*	136	542	440	....
Max.	1906-1909	91	*132*	130	113	79	*115*	353	307	1.15
Min.	1910-1914	101	102	*107*	44	31	45	310	120	2.6
Max.	1915-1918	152	*174*	172	127	*180*	136	498	443	1.12

Fig. 1.
Spot-Maximum,
1906–1909.

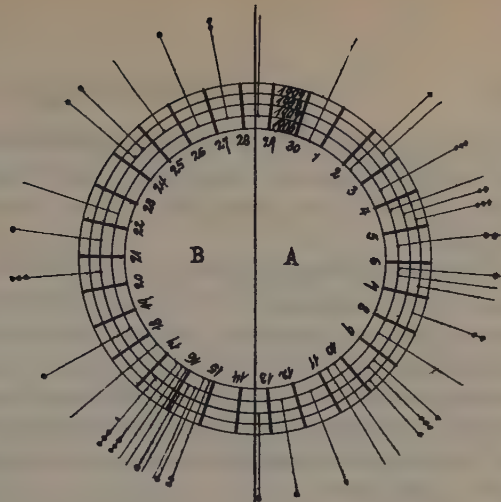


Fig. 2.
Spot-Minimum,
1910–1914.

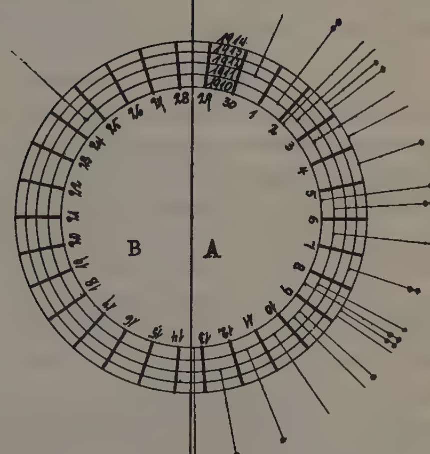
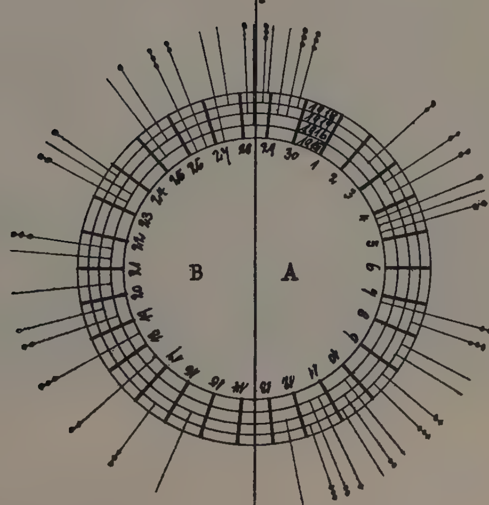


Fig. 3.
Spot-Maximum,
1915–1918.



At the times of maximum 1908–1909 and 1915–1918, both the A- and B-halves have one maximum. The degree of disturbance in the A-half is more strongly marked throughout than that in the B-half.

The contrast between the A- and B-halves, perhaps, comes out even more markedly in the distribution of storms of character 1.5 to 2.0 upon A and B. In the next table the number of storms for each grade, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, is given separately. It is remarkable how similar A and B are to one another, both at the maximum of 1906–1909 and at that of 1915–1918. On the contrary, at the time of minimum the contrast between A and B becomes very pronounced.

TABLE 5.—*Distribution of annual average of the number of storms of character 1.5-2.0 upon A and B.*

		Character Grade						
		1.5	1.6	1.7	1.8	1.9	2.0	1.5–2.0
Max. Time,	A-Half	1.75	2.30	2.00	1.75	0.75	0.75	9.30
1906-1909,	B "	1.75	1.75	2.00	2.00	0.50	0.75	8.75
Min. Time,	A "	1.60	1.60	1.60	2.00	1.00	0.00	7.80
1910-1914,	B "	1.00	0.60	0.20	0.00	0.00	0.00	1.80
Max. Time,	A "	4.00	2.50	1.75	0.75	2.50	1.25	12.75
1915-1918,	B "	4.00	2.00	2.00	1.00	1.25	1.75	12.00

Figs. 1 to 3 show graphically the distribution of the storms of character 1.7 to 2.0 on each individual day of the 30-day periods at maximum and at minimum. If it is true that the Sun is the source of disturbance, then the figures give an illustration of the distribution of such sources upon a Sun rotating in 30 days. Briefly, it may be said on the basis of the above data that the greater magnetic storms (characters 1.2 to 2.0) have a 30-day period, which is shown more conspicuously at minimum.

If the seat of disturbance is situated in the Sun, then in the time of minimum 1910–1914, only the A-half of a layer rotating in 30 days has been found active, whereas at the times of maxima both halves have been equally active. Each half contains then a center of activity, which is almost diametrically opposite to that of the other half. The activity of each center of activity varies

with the time, but each in a different way. The difference between the activity coming from the A-half and that from the B-half is small but appreciable at maximum, but very distinct at minimum (that is, B is inactive).

It appears that at least during the minimum of 1910–1914 the real centers of activity did not cross the boundaries of the A-half: hence they must have their positions constant, at any rate in heliocentric longitude. This proves that they are not situated in the light and movable layer of the flocculi and faculæ, but at greater depths where greater pressure can render certain a more constant position. The 30-day period also gives evidence as to the greater depth of the center of activity. At greater depths, under greater pressure, it is perhaps possible to expect a constant duration of rotation, which according to Adams and St. John must be greater than that of the higher layer, hence, greater than 27 days.

(F) THE SMALL STORMS.

In addition to the 30-day period of those storms which are consistent as to their time-length for the long series of years from 1906 to 1918, there is another far less consistent period of about 27 days to be found among the repetitions of much smaller storms, and this endures mostly for a few cycles only. Within the limits of these shorter cycles, this period often stands out with extraordinary clearness.

At the time of minimum solar activity, the maximum and minimum of the horizontal intensity from day to day show an easily distinguishable period of 27 days—especially at stations in the tropics. This is also the case with the daily mean of the horizontal intensity. The curves of the 24-hourly mean from 6 to 6 hours at Potsdam, Batavia, and Apia, and the curves of the daily maximum and minimum at Apia were tested for this 27-day repetition of storms. Generally, it may be said, especially at the times of increasing activity, there is a good deal that is arbitrary in the selection of the times which may be recognized as the beginnings of a series of repetitions. But in the year 1911 there could be no doubt as to the selection of a point of time where such a series of repetitions commences. Table 6 gives the time-interval between a storm and its next repetition. This rough evaluation already shows practically the same result for all three stations. The close agreement of the mean values is, no doubt, to some extent accidental.

TABLE 6.—*Repetitions of storms, 1911, in days.*

	Potsdam	*Batavia*	*Apia*
	28	27½	28
	27	28	27
	26½	26	27
	27	26	29
	28	28	26
	27¼	28	27
	26	28½	26
	25½	26	26½
	27	26½	26½
	26½	26½	26½
	27½	27¼	28
	28	27¼	27
		27	27
		27	
		26	
		26	
Mean	27.0	27.0	27.0

The observatories of the United States give in their publications a summary of the principal magnetic storms. The American station situated in the lowest latitude is Porto Rico. The storms are rated 1 to 4, relatively to their magnitude, No. 4 being the strongest. The number of storms of magnitudes 1–4 observed at Porto Rico in the year 1911 amounts to 32, of which 12 are rated 2 and 3, and the remaining 20 are rated 1.

Of these storms there are 12 which may be arranged under Series I of Table 7, and 7 others under Series II. (To Series I one storm, which occurred in Dec., 1910, has been added.) These two series include 19 of the 32 storms of the year 1911, and these are actually 11 out of the 12 strongest storms of grades 3 and 2 included in the two series. Table 7 gives the moment of commencement according to the list published for the Porto Rico Observatory; the differences of time between two consecutive storms is computed therefrom. The means of these differences came to $27^d\ 3^h$ for Series I, and $27^d\ 11^h$ for Series II. The differences vary among themselves between the limits 29 to 26 days. A part of this difference is certainly due to the uncertainty in judging the beginning of a storm. It is seldom possible to say what is the actual commencement of a storm. But the greater part of the difference is dependent on causes which must be sought in the solar phenomena themselves.

The Series I and II follow one another with a mean interval of 7 days. If the character numbers for 1911 be plotted according to rotations of 27 days, the graphs of the two series become two lines of maxima which run parallel to one another at a distance

TABLE 7.—*Magnetic storms in Porto Rico.*

SERIES I

Date	h	Gr'd	Char.	Time	Diff.
1910 Dec. 28	1	II	1.5	27 Day	0^h
1911 Jan. 24	1	II	1.7		
				27 "	16
Feb. 20	17	III	1.8		
				27 "	3
Mar. 19	20½	III	1.9		
				26 "	21
Apr. 15	17	II	1.7		
				28 "	19
May 14	12	II	1.6		
				26 "	0
June 9	12	II	1.2		
				26 "	16
Jul. 6	4	I	1.0		
Mean..				27 Day	3^h

Aug. 4	0.9 Highest Ch. No. from Jul. 31—Aug. 18
Aug. 31	0.9 Aug. 28—Sep. 11
Sep. 27	0.5 Sep. 24—Oct 1

SERIES II

Date	h	Gr'd	Char.	Time	Diff.
1911 Jan. 15	1	I	0.9		
				28 Day	18^h
Feb. 12	19	II	1.2		
				28 "	17
Mar. 13	12	I	0.9		
				25 "	19
Apr. 8	7	III	1.7		
				28 "	5
May 6	12	I	1.4		
				29 "	0
June 4	12	I	1.2		
				26 "	8
June 30	20	I	1.3		
				26 "	16
Jul. 27	12	I	1.6		
				26 "	15
Aug. 23	3	II	1.8		
				27 "	9
Sept. 19	12	II	1.7		
				27 "	17
Oct. 17	5	I	1.4		
				27 "	3
Dec. 10	11	II	1.9		
				27 "	3
Mean..				27 Day	11^h

equivalent to a 6- or 7-day interval. In Table 7, the international character number and the amount of disturbance according to the American scale I–IV will be found. Series I shows without interruption first an increase of strength from repetition to repetition, and then a sharp decreasing. In Series II a less regular rise and fall take place. As to the reality of a mean period of 27 days in the repetition of storms, these two series leave hardly any doubt.

In a similar manner, the especially quiet times may be seen recurring at intervals of 27 days, for example, the character numbers arranged according to the 27-day period show this, although the minima naturally are marked less clearly and sharply than the storms.

Chree (*Phil. Trans.*, vol. 213, p. 245) has made a study of the

magnetic character of the days, preceding and following the five most disturbed days of each month, and has found that in the mean (1906–1911 and 1890–1900) the days preceding and following the 27th, 54th, and 81st are more strongly disturbed than any of the others (except the two days immediately preceding and following). Also he found that among the days which precede and follow the quietest days, those before and after the 27th, 54th, and 81st are the quietest in character (also except the two days which immediately precede and follow the starting point).

In order to form an opinion whether this 27-day period is sharply defined, I transcribe a portion of the Table II given by Chree on page 261.

Table 8.—*"Character" figures on previous and subsequent days associated with the selected disturbed days of the 11 years, 1890-1900.*

No. of the Day	0	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
"Character" No.																
Preceding Days..	1.51	0.64	0.69	0.68	0.72	0.79	0.90	*0.96*	0.89	0.80	0.73	0.64	0.67	0.63	0.63	0.59
Subsequent Days.	1.51	0.64	0.64	0.63	0.65	0.71	0.83	*0.94*	0.92	0.84	0.79	0.72	0.70	0.67	0.64	0.61

0 signifies the day of disturbance.

The rows show a decided maximum for the 27th day. If only storms of character greater than 1.5 were used, then the years 1906–1911 show a shifting of the maximum to the 28th day.

Table 9.

No. of the Day	0	25	26	27	28	29	30
Subsequent Character No...	1.68	0.56	0.69	0.82	0.87	0.84	0.75

It seems then that the stronger storms are repeated after rather longer periods, which means that if we accept the Sun as the source of the storms, the position of this source of stronger storms lies in more slowly rotating and therefore deeper layers. The same condition is brought into prominence by the following table. A six-year interval, May, 1909–1915, arranged according to 30-day periods, contained 15 great storms in the first half, that is days 1 to 15 of the rotation, but in the second half, that is, days 16 to 30 of the rotation, there is only one large storm. On the contrary, the smaller storms are distributed much more equally. Out of a total of 48, there are 30 on the first half and 18 on the second half.

TABLE 10.—*Distribution of storms on the individual rotation days.*

30-Day Rotation. (May 25, 1909—May 22, 1915.) Number of Storms.				*27-Day Rotation.* (Dec. 12, 1914—Jul. 2, 1916.) Number of Storms.			
Character No.	1–30 Rot. Day	1–15 Rot. Day	16–30 Rot. Day	Character No.	1–27 Rot. Day	14–20 Rot. Day	21–27–13 Rot. Day
2.0—1.8	16	15	1	2.0—1.8	11	6	5
1.7—1.5	48	30	18	1.7—1.5	26	18	8

A shorter interval—1½ years, from December, 1914 to June, 1916—arranged according to 27-day period, shows quite the reverse distribution. The great storms distribute themselves more equally than the small ones. In this time one center of the Sun is especially active (14–20 day of rotation, almost ¼).

Among the 11 great storms of character 2.0–1.8, there are 6 from this center, while the other 5 are distributed over the remainder of the Sun. Among the 26 smaller storms of character 1.7–1.5, there are on the contrary 18 from this center and only 8 from the remainder of the Sun. If the character numbers be arranged according to the 30-day rotation, then the greater storms are grouped better than the small ones, at least at certain times. But if they be arranged according to the 27-day rotation, then the small storms are grouped better than the great ones. Therefore the great storms have a longer period or their source lies in a layer of the Sun deeper than that of the small storms.

The Series *A* (November 30, 1909) and *B* (Sept. 25, 1909) lead to the same result. All the storms of character 1.8–2.0 may be regarded as repetitions of these two storms. If we take the midway date, Sept. 27, 1909, as the starting point, and let T be the interval between this starting point and the observed days of disturbance throughout the time specified, then T_1, T_2 . . . are almost invariably multiples of 30 days. The mean residual was determined, taking each value from 30 days and disregarding the signs, also the moduli 26, 26.5, and 27 were treated in the same manner.

TABLE 11.

Modulus	26.0	Mean residual	6.3
	26.5		6.5
	27.0		6.2
	30.0		2.8

As these figures show, the mean residuals for the moduli 26, 26.5, and 27 are almost equal to 6.5, 6.6, and 6.75, that is, they are nearly a quarter of the length of the period, which was to be expected. For the modulus 30, on the contrary, it is very much smaller, only 2.8 instead of 7.5. This shows that the dates of the storms are capable of being arranged in periods of 30 days, much more consistently than in those of 26, 26.5, or 27 days.

(G) RECURRENCE OF STORMS AND THE SUN'S ROTATION.

The deduced result then of the investigation up to the present is that the greater storms are experienced at intervals which are multiples of 30 days, and that these series of recurrences endure for a considerable time. But it also shows that the distribution of magnetic disturbances over recurring periods approximately equal to the Sun's rotation of 27 days can only last for a much shorter extent of time, without irregularities entering in. Moreover, this result is equally true as regards the periods of disturbances and of calm, when taken according to this 27-day period. From these considerations, it would be natural to look for the causes of the short-lived 27-day periods, which continue for brief intervals only, in the higher and more variable layer of the Sun, whereas the origin of the more permanent 30-day periods may be sought in the deeper layers. And it may be presumed that these deep-lying centers eject the sources of disturbance into a higher layer which rotates in approximately 27 days, in which they continue to exist for only a few more rotations.

For the present purpose it is immaterial what the physical nature of the storms may be. They may be an electrical radiation similar to the α or β rays coming from certain areas of the Sun's surface, they may be a long coronal streamer reaching to our atmosphere, or they may be a shadow effect caused by a cloud or vapor hanging in the Sun's atmosphere which affects the ionization of the Earth's atmosphere through the normal radiation. Or again, they may be attributed to dust particles, coming from eruptive centers on the Sun, which are driven off by light pressure and penetrate the Earth's atmosphere. The only theory which will be taken for working hypothesis and for demonstration, is that there are centers of activity situated at a considerable depth in the Sun whose activity produces variations from time to time in the less dense layer above (the effects may be either electrical sources of disturbance or clouds).

These variations are the real sources of disturbance, they last only a few rotations, while the centers of activity in the deeper layers last for several years. The lower layer rotates in about 30 days, the higher in about 27 days.

It is not probable that there is any proper motion of these deeper lying and hence not very movable centers of activity in longitude and latitude; these centers must have, therefore, a more constant value for their period of rotation, and after exactly 30 days they should still be found in the same heliocentric latitude and longitude. If the greater storm centers still return after periods which are not exact multiples of 30 days, but which show a retardation of 1 or 2, or even 3 days, then possibly the following explanation may be offered. It is only when the storm center is situated in the same position with reference to the Earth at the first and second of the two consecutive outbreaks, that the time-interval will show an exact multiple of 30 days, for it is only in this case that the cause of disturbance brought by the eruption from the deeper 30-days layer into the higher 27-days layer has been during an equal time-interval in this higher layer in both cases. In all other cases it must be situated for either shorter or longer times in this more rapidly rotating upper layer and must reach the same heliographic longitude for magnetic storms effective at intervals earlier or later than those which are exact multiples of 30 days. The maximum acceleration or retardation may then amount to $30-27=3$ days. As a matter of fact, Table 1 shows only one irregularity exceeding this. Another cause of irregularity may be found, of course, in the fact that during the interval between the eruption in the deeper layer of the Sun and the transit of the active storm center through the effective position toward the Earth, the cause of disturbance (now in the higher layer) may move, owing to its own proper motion.

In this hypothesis, which our experience of the magnetic storms leads us to adopt, we may see a confirmation of the theory mentioned in Section A of this paper and not yet proved—that the velocity of the Sun's rotation increases with the height.

The next question is: *Are these 27-day periods the same every year?*

The following table shows the mean intervals between two corresponding storms belonging to each other, according to a rough consideration of the consecutive 24 hourly means, from 6 to 6 hours, and at Porto Rico according to the figures quoted above.

TABLE 12.

	1905	1907	1908	1910	1911	1912	1913	1915
Batavia	......	......	25.6	......	27.2	......	27.5	......
Apia	......	28.0	26.1	......	27.0	......	......	26.2
Porto Rico	26.8	......	......	......	27.3	26.8	......	......
Potsdam	......	28.1	26.5	27.3	27.2	27.6	......	......

There is no probability of a regular motion to be found in these figures, at least not such as Plaskett found from his spectroscopic measurements for the rotation of the Sun's equator, namely a variation of the synodic period of rotation from 26.3 to 27.7 days. If the origins of the storms share with the sun-spots the changes of position found by Spörer, that is from 30° heliocentric latitude, when the curve begins to rise, to about 10° at the time of next minimum, then the period of the storms-recurrence must be shortened in this time by about 1 day. This again seems not to be supported by Table 12. It is not at all to be expected that the origins of the storms can be sought in these spots.

Here let me point out one contradiction that may be found between the observations and our hypothesis. According to the theory, it might be expected that the center of activity of the lower layer (of 30 days rotation), propelled by an outbreak into the higher layer (of 27 days rotation) has its greatest power to disturb at the beginning and is then constantly decreasing in power from rotation to rotation. In the case of the great storms, the intensity should decrease from one 27 days rotation to the next; and the preceding 27th, 54th, and 81st day should not show any remarkable disturbance. This does happen occasionally, but the general law appears to be that an increased strength of the disturbance from rotation to rotation up to maximum, and then a diminished strength from rotation to rotation is the normal course of events, and Series I shows this clearly. Several other examples of the same thing happening could be given.

Also the result of Chree's investigations shows in the mean of several years that the disturbance of the preceding 81st, 54th, and 27th days increases from rotation to rotation, and then the maximum on the day of the disturbance diminishes in the same manner through the following 27th, 54th, and 81st days. It may, of course, have various causes for increasing and diminishing. The sources of disturbance in the layer which rotates in 27 days may develop at a

steady rate (for instance, cloud formation due to cooling), up to a maximum value, and may then disappear equally gradually. Or another cause might be found in the variation of heliographic latitude of the storm centers, which would bring them to their most efficient positions toward the earth and then equally gradually move out of this position. Or again, the yearly variation of the positions of the axes of rotation and the magnetic axes of Sun and Earth towards one another might produce a consecutive increase and diminution in the strength of the storms. In the last case, the increase and decrease must be capable of being expressed as a function of the season of year. These are all points to which further researches might be devoted, and which might perhaps lead to a modification of our hypothesis.

In a previous research (solar activity, radiation, etc.), it was shown, as has already been mentioned, that spots, faculæ, solar radiation and terrestrial magnetism show a 26- or 27-day period for the duration of the Sun's rotation, but that these three phenomena are sometimes in the same phase, and sometimes in opposite phases. In 1911 the more thinly-spotted hemisphere of the Sun corresponded with higher activity and higher atmospheric temperatures; in 1915 it corresponded with less activity and higher solar radiation, and in 1916 with lower radiation, while minimum activity then occurred about a quarter of a period in advance of the spot minimum. These discordant results in different years make it clear that the periods of spots, radiation, and activity, are not precisely the same, but are slightly different, so that the positions of the extremes move one against the other in time. The materials at my disposal up to the present are not sufficient to determine in this way the difference of these three periods with certainty, and to deduce therefrom the heights of the layers to which these three periods belong.

The observations on which the above suppositions are founded are not by any means sufficiently perfect or continuous. The suppositions have been put forward here because they might be useful to form a more comprehensive working hypothesis which I may here set down as the conclusion of this paper.

Working Hypothesis.—The variations which take place upon the Sun take for us the forms of spots and flocculi, and of fluctuations in the solar radiation, atmospheric temperature and magnetic activity. The spots and flocculi and these other variations may have a common origin, which is situated in a layer beneath the spot-

level, which rotates in 30 days. The seat of common origin varies but little over a period of several years. By eruptions of these centers, variations are caused in the higher layers where the rotation is slower. These variations take place in various layers; in the reversing layer they are seen as spots and faculæ; in higher layers they take the form of sources of fluctuation of the magnetic activity, and in still higher layers they may take the form of clouds, and be the cause of the fluctuations in the solar radiation.

As the faculæ or flocculi, the causes of magnetic activity and the fluctuations of the radiation, participate in the rotation of their respective levels, they all show periodicities dependent upon the rotation periods of their layers. Hence we assume that the higher layers rotate more rapidly; the spots and areas of flocculi have the longer period, the magnetic activity has a shorter period, and perhaps the variations of solar radiation have a shorter period still. As these lengths of period differ from one another, their extremes move one against the other. Consequently, the spot-areas, the activity and radiation are sometimes in phase, sometimes in opposition. The discrepancy as regards length of period may also be caused more or less by the fact that the sources of activity are restricted to latitudes lower than those of the spots and faculæ. The centers of activity in the layer which rotates in 30 days, frequently prove effective after long pauses in their activity. The frequency and intensity of this activity show an eleven-year period. Consequently, the spots, the magnetic activity, and the radiation also follow this eleven yearly fluctuation.

The experience that the 11-year period of sun-spots, magnetic activity, and atmospheric temperature stands out clearly and that the relative positions of their extremes remain constant, although success has not been attained in dealing with these three phenomena singly from case to case, is now capable of a natural explanation. For if we integrate over longer time-intervals, of several rotating periods, the difference in time-lengths of the periods, being of the order of a few days, is not effective, and the parallelism of the three phenomena is apparent. But if, on the contrary, we try to find a definite connection between a given spot and a given magnetic storm, both of which may be the effect of one and the same cause, then the difference in phase, owing to the difference in the time-length of their periods, becomes appreciable in a most disturbing way, especially as this difference in phase may be variable from case to case.

Summary of Conclusions.

(1) The greater magnetic storms, character 1.8–2.0, are repeated after integer multiples of 30 days.

(2) If the character numbers be arranged in periods of 30 days and these periods divided into two halves, *A* and *B*, of 15 days each, then the *A*-half produces all the great storms which occurred during the spot minimum of 1910–1914. In the times of maxima, 1906–1909 and 1915–1918, the *A*-half produces only a very small excess of storms over the number coming from *B*.

(3) The eleven-year period is perceptible in *A* as well as in *B*, but is more strongly marked in *B*. It is possible to attribute the greater storms to different longitudes of a layer of the Sun rotating in 30 days. Then at the time of minimum only one-half of the Sun would contain centers of activity, but at maximum both centers would be found active. The 11-year period is found in both these halves, strong in one, slight in the other.

(4) As shown previously by C. Chree, the distribution of magnetic activity over an interval of time approximately equal to the duration of the Sun's rotation, is repeated in a period of 27 days, and sometimes these repetitions continue without much change over several consecutive rotations. It is possible to attribute the disturbed as well as the quiet days to different heliographic longitudes of a solar layer which rotates in 27 days.

(5) It is probable that the 30-day period in magnetic activity corresponds to a layer more deeply situated in the Sun, and the 27-day period to a higher layer.

(6) In the year 1911 a very clearly marked series of storms (I) began, which followed one another at intervals of 27 days. The strength of these storms increases from rotation to rotation up to a maximum strength, and then diminishes equally regularly and in the same manner from rotation to rotation.

NOTES

1. Annual Meetings of the American Geophysical Union and its Sections. The American Geophysical Union and its several sections met, March 6–8, 1922, at the offices of the National Research Council, Washington, D. C., to hear reports of committees, to consider the agenda for the meetings in Rome, May, 1922, of the International Geodetic and Geophysical Union, and to elect officers. The meetings were well attended and several of the sections reported gratifying progress in their respective fields. The delegates selected to represent the Union and its sections at the Rome meetings are:

Geodesy, Wm. Bowie, United States Coast and Geodetic Survey, Washington, D. C.; *Seismology*, Harry Fielding Reid, Johns Hopkins University, Baltimore, Md.; *Meteorology*, H. H. Kimball, United States Weather Bureau, Washington, D. C.; *Terrestrial Magnetism and Electricity*, Louis A. Bauer, Carnegie Institution, Washington, D. C.; *Physical Oceanography*, G. W. Littlehales, Hydrographic Office, Washington, D. C.; and *Volcanology*, H. S. Washington, Geophysical Laboratory, Washington, D. C.

The *officers*, beginning July 1, 1922, are:

The Union, Louis A. Bauer (chairman), A. L. Day (vice-chairman), Wm. Bowie (secretary); *Geodesy*, John F. Hayford (chairman), R. L. Faris (vice-chairman), Wm. Bowie (secretary); *Seismology*, W. J. Humphreys (chairman), J. B. Woodworth (vice-chairman), D. L. Hazard (secretary); *Meteorology*, E. H. Bowie (chairman), R. DeC. Ward (vice-chairman), A. J. Henry (secretary); *Terrestrial Magnetism and Electricity*, W. F. G. Swann (chairman), Louis A. Bauer (vice-chairman), J. A. Fleming (secretary); *Physical Oceanography*, J. P. Ault (chairman), G. W. Littlehales (vice-chairman), W. E. Parker (secretary); *Volcanology*, L. H. Adams (chairman), T. A. Jaggar (vice-chairman), R. B. Sosman (secretary); and *Geophysical Chemistry*, H. S. Washington (chairman), Whitman Cross (vice-chairman), R. B. Sosman (secretary).

2. Institut de Physique du Globe. The courses and work at the recently established Institut de Physique du Globe of the University of Paris, were inaugurated on November 21, 1921. M. Maurain, director of the Institut, will give lectures on the general physical properties of the Globe; terrestrial magnetism and atmospheric electricity. M. R. Dongier, physicist, will give lectures on the physical properties of the atmosphere; actinometry and optical phenomena. M. Brasier, assistant physicist, will direct the work in the laboratory.

3. Personalia. Prof. Alfred Angot has retired as honorary director of the Bureau Central Météorologique of Paris. The Bureau itself has been discontinued and the magnetic work which was previously done by it has been taken over by the *Institut de Physique du Globe* of the University of Paris, which is located provisionally at 176 rue de l' Université. *Victor F. Hess*, technical director of the United States Radium Corporation, has been appointed consulting physicist of the United States Bureau of Mines. *John A. Fleming* was appointed, on January 1, 1922, assistant director for field and administrative work in the De-

partment of Terrestrial Magnetism, in order to afford the director, Dr. Bauer, additional time for investigational work. *N. H. Heck* was appointed in 1921, chief of the division of terrestrial magnetism, United States Coast and Geodetic Survey.

4. *MacMillan Baffin Land Expedition.* The Commissioner of Customs and Excise of Canada has informed us that he received, late in January, a letter from the Special Customs Officer at Port Burwell, dated November 18, 1921. The Special Customs Officer states that he had received information from the the Hudson Bay post manager at Amadjuak that Dr. MacMillan was spending the winter at a place called Nauwatta, about eighty miles north of Cape Dorset, Baffin Land. According to this information, Dr. MacMillan intends to get a supply of gasoline from the Hudson's Bay Co. next summer and return to the United States next summer, if possible.

It was the intention originally to establish winter quarters somewhere along Fury and Hecla Strait, considerably north and west of Nauwatta. The location at Nauwatta is, however, a better one from the scientific point of view since the program of magnetic, atmospheric-electric, and auroral observations can doubtless be more effectively carried out there than at a location in Fury and Hecla Strait, which would be much nearer to the magnetic pole.

5. *Amundsen's Arctic Expedition, 1922.* Captain Roald Amundsen is planning to leave Seattle, where the "Maud" has been undergoing repairs, in June, 1922, and make another attempt to drift across the Polar Sea. The main object of the expedition is the study of the physical conditions of the Arctic Sea by determining depths, temperatures, salinities, and currents. In addition to this oceanographical work, a number of observations of geophysical interest are to be undertaken, namely, magnetic and atmospheric-electric observations to be carried out in cooperation with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington; meteorological observations, which will be extended to the upper air by means of pilot balloons and kites; observations of radiation of heat, including solar radiation during the arctic day, and nocturnal radiation during the arctic night, as well as temperature variations in the ice covering the sea, and polar light observations. Opportunity will also be taken of making pendulum observations for determination of gravity over a sea 2,000 fathoms deep. It is furthermore intended to make use of airplanes for geographical exploration, using the vessel as base. Dr. H. U. Sverdrup, chief scientist, who has been associated with the Department of Terrestrial Magnetism from October, 1921 to March, 1922, left Washington for Seattle on March 31. During two visits to Washington, in January and March, Captain Amundsen concluded arrangements for the scientific work of his expedition, as briefly described above. On March 30 to April 1, he tested out on a trip from New York to Washington and return one of the two airplanes generously supplied by Mr. J. M. Larsen, of New York.

6. *Regarding the Magnetic Observations from the "Gjöa" Expedition.* According to a statement in Norwegian papers, the Norwegian Government has granted a sum necessary for the final preparation for publication of the magnetic observations from the "Gjoa" Expedition, the reduction of which has been recently completed. The publication itself, however, on account of the present high cost of printing, very regrettably will have to be indefinitely postponed.

7. *Roald Amundsen's Nordostpassagen* (*The Northeast Passage.*). Kristiania, Gyldendalske Boghandel, 1921, 467 pp., 33 plates and 5 maps. 25 cm. In July, 1918, Captain Amundsen left Norway on board his new vessel the "Maud", with the intention to follow the coast of Siberia eastward to the vicinity of Bering Strait, proceed thence towards the north, let the vessel freeze in, and drift with the ice fields across the Polar Sea back to the Altantic Ocean. However, the ice conditions forced him to winter three times in different places on the coast of Siberia. In July, 1920, after having wintered twice, Captain Amundsen called at Nome to take on board additional equipment for the drift. At his arrival in Nome, the Northeast Passage had been completed the second time in the direction from the Atlantic to the Pacific Ocean. In his new book, which is a worthy successor to his earlier publications, "The Northwest Passage" and "The South Pole", Captain Amundsen describes the voyage of the "Maud" from Christiania, Norway, to Nome, Alaska. In an entertaining and humorous way he tells about the struggle against the ice along the coast, the life on board during the winterings, bear hunting, dogs, and traveling with dog-teams. Considerable information regarding the progress of the scientific work is included in the text, particularly regarding the magnetic work, in which Captain Amundsen always has taken a great interest. A part of the book entitled "Blandt Rentsjuktsjere og Lamuter" ("Among Deer Chukchis and Lamuts") has been written by H. U. Sverdrup, who, during the winter of 1919–20, spent seven and one-half months alone among the natives to study their habits and customs.

The book, which as yet has only been published in Norwegian, is illustrated by numerous photographs, and accompanied by several maps, which partly represent the result of the survey carried out by members of the Expedition.

8. *The Magnetic Survey Work of the Department of Terrestrial Magnetism, 1922.* The *Carnegie*, since her arrival at Washington last November, has been out of commission and will remain so until the end of the present year. During the period of temporary cessation of the ocean work, special effort will be made to complete certain important land work and to obtain the requisite secular change data by re-occupying previous stations. It is expected that the Department will have six field parties in various parts of the world.

PROPOSED MAGNETIC AND ALLIED OBSERVATIONS DURING THE TOTAL SOLAR ECLIPSE OF SEPTEMBER 21, 1922.

By Louis A. Bauer and J. A. Fleming.

Special magnetic and allied observations will be made at stations inside and outside the shadow belt of the total solar eclipse of September 21, 1922, by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and by various co-operating magnetic observatories, institutions, and individuals. The distribution of the magnetic observatories within the limits of the eclipse and on both sides of the belt of totality is unusually good, as will be seen from the accompanying map taken from the American Ephemeris and Nautical Almanac for 1922 and on which the positions of these observatories have been indicated. These observatories are: North of the belt of totality, Alibag, Dehra Dun, Kodaikanal, and Toungoo, India; Batavia-Buitenzorg, Java; and Antipolo, Philippines; before beginning of eclipse, Helwan, Egypt; after ending of eclipse, Apia, Samoa; to the south, Port Louis, Mauritius Island; Watheroo, Western Australia; Toolangi, Victoria; and Christchurch, New Zealand. This distribution is all the more fortunate since the greater part of the belt of totality is over ocean areas. The stations of the Department of Terrestrial Magnetism will be probably: (1) Coongoola (or Cunnamulla), Queensland, in the belt of totality; (2) Watheroo Magnetic Observatory, Western Australia, south of the belt of totality; (3) in cooperation with Government Astronomer G. F. Dodwell and Professor Kerr Grant of the University of Adelaide, South Australia, at some point in the belt of totality in central Australia.

The general scheme of work proposed by the Department of Terrestrial Magnetism is as follows:

1. *Simultaneous magnetic observations* of any or all the elements according to the instruments at the observer's disposal, every minute from September 21, 1922, $1^h\ 28^m$ to $8^h\ 02^m$ A. M. Greenwich civil mean time.

(To insure the highest degree of accuracy, the observer should begin work early enough to have everything in complete readiness in proper time. *Past experience has shown it to be essential that the same observer make the readings throughout the entire interval.* If possible, similar observations for the same interval of time as on September 21 should be made on September 20 and 22.)

2. At *magnetic observatories*, all necessary precautions should be taken to insure that the self-recording instruments will be in good operation not only during the proposed interval, but also for some time before and after, and eye-readings should be taken in addition wherever it is possible and convenient. (*It is recommended that, in general, the magnetograph be run on the usual speed throughout the interval, and that, if a change in recording speed be made, every precaution possible be taken to guard against instrumental changes likely to affect the continuity of the base-line.*)

3. *Atmospheric-electric observations* are desirable to the fullest extent made possible by the available equipment and personnel. Observations of potential gradient are most easily provided for and most conveniently taken; in addition to these, observations (preferably for both signs) of either conductivity or ionic content are also very desirable. Full notes regarding cloud and wind conditions and, if possible, observations for both temperature and relative humidity should accompany the atmospheric-electric observations. These observations should cover the same interval as the magnetic observations. The value of the observations on the day of the eclipse will be greatly increased if similar observations can be made during the same time of day on two or three days before and after the eclipse.

4. *Meteorological observations* in accordance with the observer's equipment should be made at convenient periods (as short as possible) through the interval. It is suggested that, at least, temperature be read every fifth minute (directly after the magnetic reading for that minute).

5. *Observers in the belt of totality* are requested to take the magnetic reading every 30 seconds during the interval, 10 minutes before to 10 minutes after the time of totality, and to read temperature also every 30 seconds, between the magnetic readings.

It is hoped that full reports will be forwarded as soon as possible for publication in the journal of *Terrestrial Magnetism and Atmospheric Electricity*. Those interested are referred to the results of the observations made during the solar eclipse of May 29, 1919, which were published in the December, 1919, and in the June, September, and December, 1920, issues of this journal.

General Circumstances of the Total Solar Eclipse of September 21, 1922.

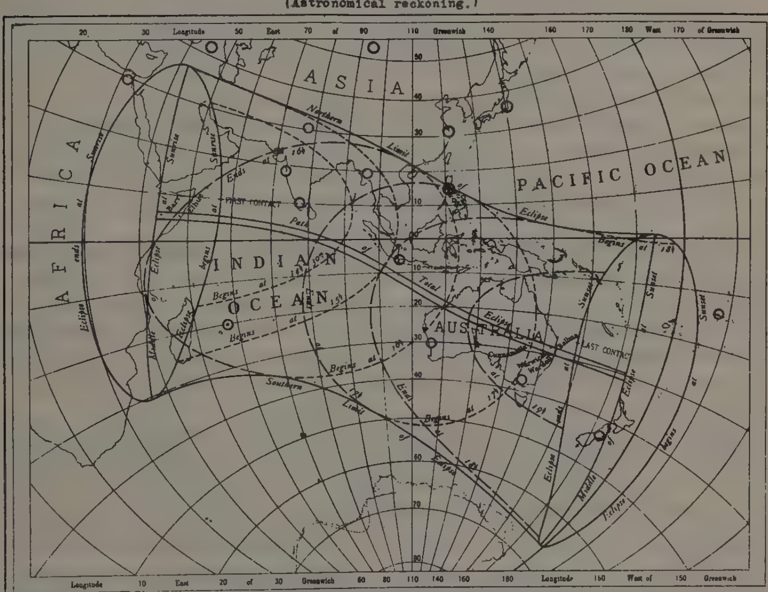
Phase	Greenwich civil mean time	Longitude from Greenwich	Latitude
	d h m	° ′	° ′
Eclipse begins................Sep.	21 2 04.3	57 06 E	9 50 N
Central eclipse begins..........	21 2 59.9	43 17 E	5 30 N
Central eclipse at local apparent noon....................	21 4 47.3	106 31 E	11 59 S
Central eclipse ends...........	21 6 20.6	172 36 E	30 15 S
Eclipse ends..................	21 7 16.2	158 47 E	25 54 S

The following table of approximate local circumstances of the eclipse is abstracted from the report of the Eclipse Committee of the American Astronomical Society published in the October, 1921, number of *Popular Astronomy*.

Approximate Local Circumstances of the Solar Eclipse of September 21, 1922.

Station	Latitude	Longitude E. of Gr.	Civil mean time middle of eclipse		Duration	Sun's altitude
			Gr.	Local		
	° ′	h m s	h m	h m	m s	°
Maldive Islands....	3 N	4 52	3 24	8 16	4 10	34
Christmas Island...	10 25 S	7 02 40	4 47	11 50	3 40	78
Wollal............	19 44 S	8 02 44	5 37	13 40	5 18	58
Coongoola.........	27 45 S	9 44 00	6 17	16 01	3 45	26
Goondiwindi.......	28 30 S	10 01 20	6 20	16 21	3 30	21
Stanthorpe........	28 40 S	10 08 00	6 22	16 30	3 25	19
Casino............	28 50 S	10 12 00	6 22	16 34	3 20	18

TOTAL ECLIPSE OF SEPTEMBER 20, 1922.
(Astronomical reckoning.)



Magnetic Observatories are indicated by circles (O).
Note: The hours of beginning and ending are expressed in Greenwich Mean Time.

ABSTRACT

Bauer, L. A., J. A. Fleming, H. W. Fisk, W. J. Peters, and S. J. Barnett: *Land Magnetic Observations, 1914–1920, and Special Reports.* Researches of the Department of Terrestrial Magnetism, Vol. IV, Publication No. 175, Carnegie Institution of Washington. Washington, 1921, vi + 475 pp., 9 plates, 17 figures. 30 cm.

This volume presents, in continuation of the previous volumes of "Researches" (No. 175, vols. I, II, and III), the results of magnetic observations made by the Department of Terrestrial Magnetism, 1914–1920, and four special reports. The land stations for which the results are reported upon may be summarized as follows: Africa, 447; Asia, 356; Australasia, 315; Europe, 24; North America, 113; South America, 339; Islands of the Atlantic Ocean, 19; Islands of the Indian Ocean, 30; Islands of the Pacific Ocean, 104; the total number of land stations is thus 1,747. The table of results gives names of stations, geographic positions, values of the 3 magnetic elements, dates and local mean times of observations, references to instruments used, and the initials of observers.

Data for the determination of secular-variation have been obtained at 204 C. I. W. repeat localities, the reoccupations for each locality listed involving from 1 to 4 stations. The great majority, 168, of these were either exact reoccupations or close reoccupations (within less than 30 meters). For many of these localities the repeat observations were obtained not only at several stations, but also at different times during 1914 to 1920. In addition to these sources of secular-variation data, fully 150 more of the stations have been practical reoccupations (within less than 300 meters) or proximate reoccupations (within less than 5 kilometers) of stations previously occupied by various exploring expeditions.

The text preceding the table of results gives a discussion of instrumental constants and corrections on adopted International Magnetic Standards as defined on pages 270–278 of Volume II. A brief discussion of the accuracy of the geographic positions is given particularly as regards longitudes. Auxiliary tables to facilitate revisions of field magnetic observations are given, together with graphs for determining without recomputation the corrections necessary in azimuth and time reductions for revised values of latitude or of time.

The volume is concluded with four special reports. "Construction of non-magnetic experiment building," by J. A. Fleming, describes the building specially designed and built for experimental investigations in magnetism. H. W. Fisk discusses "Dip-needle errors arising from minute pivot-defects"; theoretical investigations are made of various cases and illustrated by instructive graphs. "A sine galvanometer for determining in absolute measure the horizontal intensity of the Earth's magnetic field," by S. J. Barnett, describes the design and construction of a new sine galvanometer and gives the theory of the instrument in detail, including the considerations leading to the type of coils used and a discussion of possible sources of error; it is readily possible to make absolute determinations of horizontal intensity with great speed and with an error less

than one part in 10,000, provided the calibrations of the electrical measuring instruments are known with sufficient precision.

The concluding special report by J. A. Fleming on "Results of comparisons of magnetic standards, 1915–1921", is in continuation of the similar report by L. A. Bauer and J. A. Fleming, in Volume II; the results of comparisons obtained at 30 magnetic observatories during 1905 to 1921 are summarized. The provisional "International Magnetic Standards", as previously adopted for the work of the Carnegie Institution of Washington, are found to meet with sufficient precision all theoretical and practical requirements.

LIST OF RECENT PUBLICATIONS

A. Terrestrial Magnetism.

Agincourt and Meanook Observatories. Results of observations at the Canadian Magnetical Observatories, Agincourt and Meanook. The year 1918. Prepared by W. E. W. Jackson under the supervision of Sir Frederic Stupart. Ottawa, F. A. Acland, 1921 (41 with 12 curves). 29 cm.

Agincourt and Meancook Observatories. Magnetic disturbances, November and December, 1921. Toronto, J. R. Astr. Soc. Can., v. 16, No. 2, Feb., 1922 (67), and No. 3, March, 1922 (115).

Angenheister, G. Anmerkung zur Störung vom 13. bis 16. Mai 1921. Met. Zs., Braunschweig, Bd. 39, Heft 1, Jan. 1922 (20–23).

Angenheister, G., und C. J. Westland. Magnetische Störung und Polarlicht vom 13. bis 16. Mai 1921, nach Beobachtungen des Samoa-Observatoriums. Met. Zs., Braunschweig, Bd. 39, Heft 1, Jan. 1922 (19–20).

Bombay and Alibag Observatories. Magnetical, meteorological and seismographic observations made at the government observatories, Bombay and Alibag, in the years 1911 to 1915, under the direction of N. A. F. Moos. Bombay, Govt. Central Press, 1921 (xxxiv + 105 + 139 + 22). 32 cm.

Cortie, A. L. Terrestrial magnetic disturbances and sun-spots. Nature, London, v. 109, No. 2724, Jan. 12, 1922 (44).

Dufour, Ch. Valeurs des éléments magnétiques à la station du Val-Joyeux à Villepreux (Seine-et-Oise) au ler janvier 1922. Paris, C.-R. Acad. sci., T. 174, No. 3, 16 janvier 1922 (185–186).

French, C. A. Magnetic results, 1907–1920 [in Canada]. Ottawa, Pubs. Dominion Observatory, v. 5, No. 5, 1921 (131–262, with 3 maps). 29 cm.

India. Meteorological Department. Monthly weather review. Published by authority of the Government of India, under the direction of Gilbert T. Walker, Director-General of Observatories. August–December, 1916; January–December, 1917; January, 1918. Calcutta, Supt. Govt. Printing, 1916–1921, 30 cm. [Contains account of solar, magnetic and seismic disturbances during each month at the various observatories of India.]

Magnetic Observations. Observations magnétiques effectuées dans les colonies françaises ou pays d' influence française par la "Carnegie Institution" de 1905 à 1913. Ann. hydrogr., Paris, No. 705, Sér. 3, volume de 1919–1920 (285–289).

Mauritius. Annual report of the director of the Royal Alfred Observatory for the year 1919. (A. Walter, Director.) Mauritius, Govt. Press, 1920 (4). 34 cm.

Pacific Ocean. Chart of lines of equal magnetic declination, 1921. Kobe, Imperial Marine Observatory, 1921, 51 x 66 cm.

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Terrestrial Magnetism *and* *Atmospheric Electricity*

VOLUME XXVII SEPTEMBER, 1922 No. 3

TERRESTRIAL MAGNETISM AND ELECTRICITY AT THE ROME MEETING, MAY, 1922.[1]

GENERAL REPORT BY LOUIS A. BAUER.

The second triennial meetings of the International Astronomical Union and of the International Geodetic and Geophysical Union, established at Brussels in 1919 under the auspices of the International Research Council, were held at Rome, May 2 to 10, 1922, in the quarters of the Accademia de Lyncei, at the Palazzo Corsini. Some three hundred delegates and guests attended these highly successful gatherings. After preliminary general sessions of the Unions, the various sections and committees had separate meetings, and at the conclusion general sessions again were held on May 10 for the transaction of matters pertaining to the entire unions.

While there were some decided advantages of having the two unions meet at the same time and in the same place, many of the representatives, because of the necessary overlapping of sessions, could generally attend only the section or committee in which they were specifically interested. The only time when general intercourse became usually possible was at the social events, provision for which had been abundantly made by the National Committee of Italy. It was considered, however, that the experiment might be tried of having in future separate meetings of the two unions. Accordingly, the next meeting of the International Astronomical Union will be held at Cambridge, England, in 1925, and that of the International Geodetic and Geophysical Union at Madrid, Spain, in 1924—probably during September.

The following general report pertains specifically to the meeting

[1] The full report will appear in a volume to be published by the International Section of Terrestrial Magnetism and Electricity, containing the Proceedings and Reports submitted.

of the Section of Terrestrial Magnetism and Electricity of the International Geodetic and Geophysical Union. This section held seven well-attended sessions, May 4-9, twelve different countries being represented by thirty-three delegates and guests, viz.:

Australia (J. M. Baldwin, G. F. Dodwell, E. F. Pigot); *Belgium* (J. Jaumotte); *Brazil* (H. Morize); *France* (J. Bosler, H. Deslandres, E. Delcambre, E. Mathias, Ch. Maurain); *Great Britain* (C. Chree, A. L. Cortie, W. C. Parkinson, Arthur Schuster, Napier Shaw, G. C. Simpson); *Italy* (A. Alessio, F. Eredia, L. Palazzo, D. Pacini, G. Platania, A. Pochettino, G. B. Rizzo, C. Somigliana); *Japan* (K. Nakamura); *Poland* (J. Krassowski); *Spain* (J. Galbis, L. Rodés); *Sweden* (D. Stenquist, A. Wallén); *United States* (L. A. Bauer, G. W. Littlehales); *Canada* (E. Deville).

Organization.—Professor Tanakadate, who was unable to be present at Rome, had requested to be relieved of the presidency of the section, because of his inability to attend to the duties. The resignation was regretfully accepted and Dr. Charles Chree, who as vice-president had presided at all sessions, was elected at the closing session on May 9 president, and Professor Luigi Palazzo, vice-president; both of these officers, according to the statutes, serve for two terms. The secretary and director of the Central Bureau, Dr. Louis A. Bauer, continues in office until the next meeting, which will be at Madrid, Spain, about September, 1924. Directors J. Jaumotte (Belgium) and Ch. Maurain (France), and Professor A. Tanakadate (Japan), in addition to the three officers of the Section, were constituted the Executive Committee. It was agreed that administrative matters should be left to the Bureau, consisting of the officers of the Section.

Agenda.—Since the meeting at Brussels in July, 1919, when the International Section of Terrestrial Magnetism and Electricity was established, nearly three years have elapsed. While the organization of the work of the Section, because of the post-war conditions, could not proceed as rapidly as it was hoped, nevertheless, definite progress has been made regarding which the Agenda (Ordre du Jour) for the present meeting are at least one indication.[1] Perhaps for the first time we have had presented in so concrete a form the salient questions, both of a practical and theoretical nature, pertaining to the magnetic and electric states of our Earth and its atmosphere. It was not to be expected, nor, indeed, desirable, that

[1] See *Terr. Mag.*, vol. 26, pp. 151-152, 1921, for English text; the French text will be found in this publication, pages 99-100.

definite decisions on all the questions should be reached at the present meeting. However, it must be a source of gratification that by the united action of the National Committees the crucial questions and problems have received a definite formulation.

Reports.—Reports were presented showing the status of magnetic and electric work in the various countries represented, and containing the opinions of National Committees, leading organizations, and investigators on items of the Agenda. There were, furthermore, reports from committees constituted at the Brussels meeting, as also reports and letters expressing the views of some whose countries, either were not officially represented at Rome (Greece, New Zealand), or did not yet belong to the International Geodetic and Geophysical Union. Among the latter there were letters from E. van Everdingen (Holland); V. Carlheim-Gyllensköld (Sweden); C. Ryder (Denmark); and Adolf Schmidt (Germany).

Resolutions.—On the basis of all information on hand and the ensuing discussions on items of the Agenda, the appended twenty resolutions were passed. It will be noticed that the Executive Committee is empowered to formulate more definite recommendations on some of the mooted questions of procedure, especially at magnetic observatories, as soon as further information has been received by the secretary from all services and observatories engaged in magnetic or electric work, in response to a questionnaire to be sent out.

Committees.—Five committees were appointed: 1. Committee on Magnetic Surveys and International Comparisons of Instruments; 2. Committee on Observational Work in Atmospheric Electricity to Report on Objects, Instruments, and Methods; 3. Committee on Measures of Magnetic Characterization of Days; 4. Committee on Best Methods, Instruments, and Compilations for Polar Light Observations; and 5. Committee to Consider and Report on Best Methods and Instruments for Earth-Current Observations. The provisional organization of these committees is shown by the appended list. The Executive Committee, according to Resolutions 11 and 15, was empowered to add to the membership of committees, as additional countries join the Union, and to form any additional committees deemed necessary to put into effect the resolutions. Provision has also been made for consideration of questions concerning the relationship between solar and the earth's magnetic and electric phenomena in the following manner: 1. A

committee on solar radiation, under the chairmanship of Dr. George E. Hale, of which Dr. Bauer is a member, was formed by the International Astronomical Union; 2. The International Research Council at its Brussels meeting in July, 1922, has decided to assist in initiating studies of the correlations between solar and terrestrial phenomena, as this subject is one of the kind in which several unions are jointly interested.

Funds.—The balance, 30,892 francs, of the accumulated funds in hand, arising from the contributions, 1919-1922, of the adhering countries at the rate of four hundred francs per contributing unit, was made available to the Section. This is in addition to the sum of about fifteen hundred francs which had been supplied in 1921, for incidental expenses of the Section. There will, furthermore, be available during the period 1922-1924, from the contributions of adhering countries, annually an amount at the rate of 320 francs per contributing amount. It is estimated that the annual amount from this source will be about 22,000 francs. Hence the Section will have available for its various purposes during the period 1922-1924, in all about 75,000 francs,[1] which is subject to increase as additional countries join the Union. With the aid of the funds thus available it is hoped that matters of international concern and benefit may be energetically pursued, for example, frequent intercomparisons of magnetic standards, the chief expense of which during the past sixteen years has been borne by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

The secretary and Prof. E. Mathias, as alternate or substitute when necessary, were made members of the Finance Committee of the International Geodetic and Geophysical Union.

Publications.—Resolution 12 empowered the Executive Committee to incur the necessary expense for the publication in the most suitable form of the minutes and proceedings of the Rome meeting and of the various reports received, as well as for the issue of any additional publications which may be found desirable and which the available funds may permit. It is estimated that the volume of proceedings and reports will approximate three hundred octavo pages, and that it may be distributed early in 1923. By means of bulletins, issued from time to time, prompt information it is hoped may be given regarding matters of international interest,

[1] Approximately, according to present rate of exchange, about 5,900 United States dollars or 1,315 pounds sterling.

progress on mooted questions, actions taken and recommendations by the Executive Committee, committees of the Section and National Committees, latest values of the magnetic and electric elements at observatories, etc.

Officers of the International Geodetic and Geophysical Union and of its Section.—For convenience of reference there are given in the table below, besides the officers of the particular section of interest in this report, the officers of the entire Union and of the other sections. An additional section (Scientific Hydrology) was established at Rome.

OFFICERS OF INTERNATIONAL GEODETIC AND GEOPHYSICAL UNION, 1922—.

Officers of the Union

President: C. Lallemand.**
Vice-President: Presidents of the Sections.
Secretary-General: H. G. Lyons.**

Officers of the Sections

Section	President	Vice-President	Secretary
Geodesy	W. Bowie*	R. Gautier**	G. Perrier*
Seismology	H. H. Turner**	E. Oddone**	E. Rothé**
Meteorology	N. Shaw*	C. F. Marvin** E. Delcambre**	F. Eredia**
Terrestrial Magnetism and Electricity	C. Chree**	L. Palazzo**	Louis A. Bauer*
Physical Oceanography†	Prince of Monaco*	J. Parry*	G. Magrini*
Vulcanology	A. Lacroix**	H. S. Washington**	A. Malladra** G. Platania**
Scientific Hydrology	E. B. H. Wade**	A. Wallén**	G. Magrini**

Social Features.—Among the special social features may be mentioned: May 2, 3 p. m., Inaugural Ceremony at the Campidoglio, at which H. M., the King of Italy, was present; May 4, 9 p. m., Reception of the Delegates at the Campidoglio by the Municipality of Rome; May 8, 3 p. m., Visit to the Palatino at the Invitation of the Under Secretary of Antiquities and Fine Arts; and May 10,

* One additional term, beginning May, 1922, and continuing until next meeting (1924).
** Two additional terms, beginning May, 1922.
† The president has unfortunately died since the Rome meeting.

1 p. m., Visit to the Vatican and Audience with the Pope. Provision had also been made for several special excursions during and after the meetings, which gave further opportunity to the visiting delegates for social intercourse. At the closing session of the Union on May 10 several resolutions were passed in appreciation of the excellent arrangements made by Italy, both as regards the scientific sessions and the various social events.

Members of the Section of Terrestrial Magnetism and Electricity are also especially indebted to the genial director of the Italian Meteorological and Geodynamical Bureau, Professor Luigi Palazzo, for the part he took to ensure the success of the meeting.

ASTRONOMERS, GEOPHYSICISTS, AND GUESTS, ROME MEETING, MAY 1922.

Resolutions of International Section of Terrestrial Magnetism and Electricity.

(*Approved at the Rome Meeting, May 9, 1922*)

1. In view of the importance of securing world-wide cooperation in Terrestrial Magnetism and Electricity, and remembering the great contributions in these fields by scientists and instrument makers of countries not yet adherent to the Section, the hope is expressed that a day will come when the collaboration of all countries in the labors of the Section will become possible.

2. That the attention of directors of observatories be called to the importance of assuring themselves that the methods they employ for scale-value determinations of magnetographs are satisfactory, and that a general statement as to the methods be given in all observatory publications.

3. That in view of the diverse types of instruments in use, and diverse circumstances prevailing at the various stations, it is not advisable at present to recommend the adoption of any particular method of scale-value determination for magnetographs, nor any particular scale value, nor to specify an opinion as to the best elements to record.

4. That National Committees be requested to designate, if possible, one observatory in their respective countries for international intercomparisons of magnetic instruments, and to secure intercomparisons of magnetic instruments within their own countries at least once within the course of three years.

5. That the Committee on Magnetic Surveys and Intercomparisons of Magnetic Instruments formulate a definite scheme for securing intercomparisons of magnetic instruments between countries, and especially contiguous countries.

6. That the following are the localities at which additional magnetic observatories are most desirable: Northeast Canada, Northeast Siberia, Bermuda, St. Helena (or French West Africa), Italian North Africa, British South Africa, and Northeast Australia.

7. That the steps already taken by the New Zealand Government regarding the continuation of the Apia Observatory, Samoa, are highly commended, and it is hoped that the New Zealand Government may find it possible to provide for the continued full activities of the Observatory.

8. That the continuation by the Argentine Government of the Orcados Observatory is very much to be desired, in view of the high southerly latitude of the observatory and the opportunities thus afforded for obtaining highly important data.

9. That every magnetic observatory publish annually the monthly and annual mean values of the magnetic elements observed during the preceding year, for the purpose of the mutual exchange of such results.

10. That the organizations responsible for the various magnetic services be urged to make prompt publication of their data as completely as circumstances permit.

11. That the executive committee be empowered to constitute the committees recommended by the Section and to establish such additional committees as may be found necessary to put into effect the resolutions passed at the Rome meeting.

12. That the executive committee be authorized to incur the necessary expense for the publication in the most suitable form of the minutes and proceedings of the Rome meeting and of the various reports received, as well as for the issue of any additional publications which may be found desirable and which the available funds may permit.

13. That a committee be appointed to report on the best methods, instruments, and compilations for polar-light observations.

14. That in order to stimulate research regarding earth-currents, a committee be appointed to consider and report on the best methods and instruments.

15. That the executive committee be empowered to add to its membership or to the membership of the committees.

16. That it is desirable there should be in every country at least one observatory making systematic atmospheric-electric observations (especially of potential gradient, earth-air currents, conductivity, and number of ions) which are intercomparable amongst themselves and comparable with similar observations made in other countries.

17. That a committee be appointed on observational work in atmospheric electricity, to report on objects, instruments, and methods.

18. That in all publications concerning ionization, the author should indicate the value which he uses for the unit charge.

19. That, if funds allow, copies of disturbed magnetic curves continue to be published as at present, even when on a reduced scale, as they supply information at least potentially useful regarding the general features of disturbance. It is recognized, on the other hand, that for detailed examination photographic copies are much preferable, and that some scheme might usefully be arranged whereby anyone desiring such copies could secure them from certain observatories for a pre-arranged fee. As a preliminary to such a scheme directors of observatories are to be consulted.

20. That regarding items A6, 7, and 9 of the printed Agenda, namely, mean annual values and secular change, diurnal inequalities, and publications, the Executive Committee consider and formulate any recommendations they may think desirable.

(Signed) CHARLES CHREE, *President;* LOUIS A. BAUER, *Secretary.*

Committees of International Section of Terrestrial Magnetism and Electricity.

(As Provisionally Constituted at Rome, May 9, 1922).

1. *Committee on Magnetic Surveys and International Comparisons of Instruments:* Louis A. Bauer (chairman); U. de Azpiazu, J. M. Baldwin, A. Ferraz de Carvalho, C. Chree, M. Eginitis, N. H. Heck, A. Hermant, S. Kalinowski, O. Klotz, E. Mathias, H. Morize, L. Palazzo, N. Watanabe.

2. *Committee on Observational Work in Atmospheric Electricity to Report on Objects, Instruments, and Methods:* G. C. Simpson (chairman); J. Jaumotte, P. Langevin, D. Pacini, W. F. G. Swann.

3. *Committee on Measures of Magnetic Characterization of Days:* ——— ————— (chairman); R. L. Faris, A. Crichton Mitchell, R. Dongier, A. Tanakadate.

4. *Committee on Best Methods, Instruments, and Compilations for Polar Light Observations:* ——— ————— (chairman); H. Arctowski, Ch. Fabry, J. A. Fleming, Lord Rayleigh, R. F. Stupart.

5. *Committee to Consider and Report on Best Methods and Instruments for Earth-Current Observations:* A. Schuster (chairman); S. J. Mauchly (secretary), Ch. Maurain, L. Rodés, H. Nagoaka.

(Signed) Charles Chree, *President;* Louis A. Bauer, *Secretary.*

Union Géodésique et Géophysique Internationale.

conférence de rome, mai, 1922.

Ordre Du Jour.

DE LA SECTION DE MAGNÉTISME ET D'ÉLECTRICITÉ TERRESTRES.

1.—Ouverture de la Séance.
2.—Rapport du Secrétaire, Directeur du Bureau Central.
3.—Rapports variés (des Comités nationaux et spéciaux et sur les investigations).
4.—Questions diverses soumises à l'étude et à la considération des Comités spéciaux.
5.—But, champ d'activité et nom définitif à adopter pour la Section.
6.—Statuts et organisation future de la Section.
7.—Nomination et organisation des Comités.
8.—Résolutions soumises au vote.

Les questions soumises (No. 4) à l'étude et à la considération des Comités sont les suivantes:

A.—Magnétisme Terrestre.

1.—Instruments absolus.
- *a.* Méthodes électriques.
- *b.* Détermination des "constantes."
- *c.* Comparisons.

2.—Observations absolues.
- *a.* Méthodes.
- *b.* Procédés de réduction.

3.—Magnétographes.
- *a.* Détermination de la valeur des divisions de l'échelle.
- *b.* Valeurs des divisions de l'échelle à recommander.
- *c.* Éléments à enregistrer de préférence.

4.—Caractérisation des jours et l'activité magnétique.

5.—Relevé des courbes.
- *a.* Heure locale ou heure de Greenwich?
- *b.* Valeurs instantanées ou moyennes horaires?
- *c.* Si moyennes horaires, les 60 minutes sont-elles centrées à l'heure ou à la demi-heure?

6.—Moyennes annuelles et variation séculaire.
- *a.* Si d'après les courbes, avec quel mode de coupure des jours?
- *b.* Si d'après les observations absolues, avec quelles corrections?

7.—Inégalités diurnes.
- *a.* Déduites de l'ensemble ou de certains jours choisis, et comment?
- *b.* Corrections non périodiques.
- *c.* Coefficients de Fourier.

8.—Copies des courbes. Moyens de les obtenir et de les échanger.

9.—Publications
- *a.* Ce qu'il y a lieu de publier. Minimum désirable.
- *b.* Forme. *c.* Terminologie.

10.—Réseaux magnétiques.
- *a.* Densité des stations.
- *b.* Question d'une période internationale et de sa date.
- *c.* Procédés d'observation—leur exactitude.
- *d.* Reduction à une même époque.
- *e.* La construction des courbes isomagnétiques.
- *f.* Zones perturbées. Les anomalies et la géologie.
- *g.* Champ magnétique terrestre.
- *h.* Présentation des résultats.

11.—Variation des éléments magnétiques avec l'altitude.

12.—Ligne magnétique integrale et courants électriques aéroterrestres, leur détermination et leur compatibilité.

B.—Électricité Terrestre.

1.—Comment obtenir et publier de données complètes sur le gradient du potentiel, les courants aéroterrestres, la conductibilité et le nombre d'ions atmosphériques en la forme la plus uniforme et de la maniére la plus satisfaisante (formation d'un comité d'enquête sur les instruments et les méthodes).

2.—Observation des phénomènes électriques dans les couches supérieures de l'atmosphère.

3.—Aurores boréales (méthodes, instruments, compilations).

4.—Courants telluriques (méthodes, instruments, observations, publications).

5.—Rapports entre l'activité solaire et les phénomènes magnétiques et électriques observés à la surface de la terre.

Voeux de la Section Internationale de Magnétisme et d'Electricité Terrestres.

(*Adoptés à la Conférence de Rome, le 9 mai 1922.*)

1. Etant donnée l'importance qu'il y a à assurer une large coopération dans le monde en ce qui concerne le magnétisme et l'électricité terrestres, et en considération de la contribution considérable dans ces domaines apportée par les savants et les constructeurs de pays qui n' adhèrent pas encore à la Section, l'espoir est exprimé qu'un jour viendra où la collaboration de tous les pays aux travaux de la Section deviendra possible.

2. Que l'attention des directeurs d' observatoires soit appelée sur l'importance qu'il y a à vérifier eux-mêmes que les méthodes employées pour déterminer la valeur des divisions de l'échelle du magnétographe sont satisfaisantes, et qu'un exposé des méthodes établies soit donné dans les publications des observatoires.

3. Que, d'après la diversité des instruments en usage et des conditions correspondant aux diverses stations, il n'est pas désirable pour le moment, de recommander l'adoption d'une méthode particulière pour la détermination de la valeur des divisions de l'échelle du magnétographe, ni une valeur particulière; ni d' exprimer une opinion sur les éléments à enregistrer de préférence.

4. Que les Comités Nationaux soient priés de désigner, s'il est possible, un observatoire central pour leurs pays respectifs, chargé des comparaisons internationales des instruments magnétiques, et d'assurer dans leurs propres pays une comparaison des instruments.

5. Que le Comité chargé des levés magnétiques et des comparaisons internationales des instruments magnétiques, formule des règles définies pour assurer les comparaisons des instruments magnétiques, spécialement en ce qui concerne les pays contigus.

6. Qu'il soit établi des observatoires magnétiques additionnels dans les contrées suivantes, pour lesquelles cela est le plus désirable: Nord-Est du Canada, Nord-Est de la Sibérie, Les Bermudes, Sainte-Hélène (ou Afrique Occidentale Française), Nord Africain Italien, Afrique Anglaise du Sud, et Nord-Est de l'Australie.

7. Les dispositions déjà prises par le Gouvernement de la Nouvelle-Zélande pour le maintien de l'Observatoire d'Apia, Samoa, sont hautement approuvées et l'espoir est exprimé que le Gouvernement de la Nouvelle-Zélande aura la possibilité de permettre à cet observatoire la continuation de sa pleine activité.

8. Le maintien par le Gouvernement Argentin du service de l'Observatoire des Orcades est hautement désirable, à cause de la haute latitude sud de l'Observatoire et de la possibilité d'obtenir ainsi d'importantes données.

9. Que chaque observatoire magnétique publie annuellement les valeurs moyennes, mensuelles et annuelles, des éléments magnétiques relatives à l'année précédente, afin d'assurer l'échange mutuel de ces résultats.

10. Que les organisations responsables des différents services magnétiques soient promptes à assurer leurs publications d'une manière aussi complète que possible.

11. Que le Comité Exécutif ait le pouvoir d'instituer des comités recommandés par la Section, et d'établir de tels comités additionnels autant qu'il sera jugé nécessaire pour mettre à exécution les résolutions de la réunion de Rome.

12. Que le Comité Exécutif soit autorisé à faire la dépense nécessaire pour une publication, sous la forme la plus convenable des minutes et des procès-verbaux de la réunion de Rome, ainsi que des différents rapports reçus, et soit autorisé à faire toutes autres publications utiles, dans la limite des fonds disponibles.

13. Qu'un Comité soit chargé de faire un rapport sur les meilleures méthodes les meilleurs instruments et les publications relatives aux aurores polaires.

14. Qu'afin de stimuler les recherches concernant les courants telluriques, un Comité soit formé pour établir un rapport sur les meilleures méthodes et les meilleurs appareils.

15. Que le Comité Exécutif ait le pouvoir d'adjoindre à ses membres ou à ceux des autres comités des personnes qualifiées.

16. Qu'il y ait dans chaque pays au moins un observatoire faisant des observations systématiques d'électricité atmosphérique, spécialement de: gradient du potentiel, courant air-terre, conductibilité électrique, et nombre d'ions, de telle façon que ces observations soient comparables entre elles et comparables aux observations semblables faites dans les autres pays.

17. Qu'un Comité soit formé pour faire un rapport sur les sujets d'études, les instruments, et les méthodes relatives à l'électricité atmosphérique.

18. Que dans toutes les publications concernant l'ionisation, l'auteur indique la valeur qu'il admet pour l'unité de chargé.

19. Que, si les fonds le permettent, on continue à publier, comme on le fait actuellement, les reproductions des courbes perturbées, même à échelle réduite, vu qu'elles fournissent des renseignements qui pourront être utiles, sur le caractère général des perturbations. D'autre part, il est reconnu que, pour une étude détaillée, les copies photographiques sont à préférer, et qu'il serait utile d'établir un procédé permettant à ceux qui désirent de telles copies d'en obtenir de certains observatoires à un prix fixé d'avance. Avant de mettre à effet ce projet, on devrait consulter les directeurs des observatoires.

20. Que, en ce qui concerne les articles A6, 7 et 9, de l'Ordre du Jour imprimé, à savoir, moyennes annuelles, variation séculaire, inégalités diurnes et publications, le Comité Exécutif établisse et formule les recommandations qu'il jugera désirables.

(Signé) *Le Président*, CHARLES CHREE; *Le Secrétaire*, LOUIS A. BAUER.

SOME EXPERIMENTS ON THE PENETRATING γ RADIATION PRESENT IN THE ATMOSPHERE.

By E. Marsden.

The present note deals with an experiment on the magnitude of the ionization due to penetrating radiation in a closed can on Mount Ruapehu (latitude 39°.25 S.; longitude 175°.6 E.; height, 9,200 feet = 2,800 meters).

According to Kolhörster,[1] the ionization in a closed ionization vessel, in free air, at an altitude of 2,800 meters is 4 ions per c.c. greater than that at sea level. Kolhörster's experiments were made with air in a zinc (?) ionization-vessel.

It is well known that the ionization due to γ rays in a vessel containing a gas with molecules of high atomic weight is greater than that in air. In the experiments to be described sulphur dioxide was used, and although this gas does not multiply the γ-ray effect so much as gases such as methyl iodide, yet, on account of its chemical stability when dry, and its relatively high condensation point, it is particularly suitable for the experiment in view. By using SO_2 in a closed vessel, the ionization due to γ rays is approximately doubled, while the ionization due to radioactive impurities in the material of the vessel (chiefly α-ray effect) is practically unaltered. Thus, any variations of penetrating γ radiation will relatively, to the whole leak, be greater than in the case of experiments made with air.

Further, it is well known that the ionization due to γ rays is, in the main, a secondary effect of β particles ejected from the walls of the measuring vessel, very little of the effect being due to secondary β particles from the gas itself. The secondary β particles have a range at normal temperature and pressure considerably greater than the average dimensions of an ionization-vessel.

The number of secondary β particles from various materials, and consequently the ionization due to γ rays in a closed vessel, increases with the atomic weight of the material: for instance, the ionization in a lead vessel is approximately twice that in one of

* Phys. Zeitschr. *XIV*, p. 1153, 1913.

brass. The main objection to increasing the γ-ray effect in this way is the difficulty of obtaining materials of high atomic weight without a large increase in radioactive impurity: for example, lead is notoriously radioactive on account of the presence of its isotope RaD, with the consequent production of polonium. By using old lead, however, the greater part of the RaD will have decayed, with consequent diminution of natural activity.

In some preliminary tests, a cylindrical brass can was used. The natural leak was obtained with air in the can by means of a Wilson tilted electroscope. The leak, due to γ rays from radium at a standard distance (1.5 meters) was also obtained. The can was then lined with various materials by preparing a solder by admixture of tin, and "wiping" or "tinning" the inside of the can, the average thickness of the coating being about 0.2 mm.

The results were as follows:

Inside coating of ionization can	Natural leak, Volts/minute	Effect of γ rays from standard Ra., corrected for natural leak
Brass	0.05	1.0
50 per cent old lead, 25 per cent Sn., 25 per cent Bi.	0.10	1.8
Pb. (old) + 5% Sn	0.07	1.9
Sn.	0.115	1.5
Bi + 5% Sn.	0.145	1.95
Pb. (new) + 5% Sn	0.115	1.85
Pb. (old) with sulphur dioxide	0.075 (approx.)	3.7

The new lead was ordinary, newly purchased, plumber's lead. The old lead had been used for roofing a house in Nelson, N. Z., about seventy years ago, and was as old as any readily available in New Zealand. The test shows that bismuth and new lead are unsuitable owing to radioactive impurity: so also was the tin used. The old lead increased the γ-ray effect by ninety per cent, and the natural leak by only forty per cent. This latter leak is increased partly by increase of the penetrating radiation effect, and possibly partly by the greater natural leak of the lead used than that of brass. The surface of the brass was thoroughly cleaned before use.

The test shows that for measuring increases of penetrating radiation of the γ-ray type, a vessel lined with old lead and filled with sulphur dioxide possesses considerable advantages compared with a brass vessel filled with air.

For the mountain experiment, two sets of apparatus were constructed, each consisting of a Wilson tilted electroscope and an ionization-can. The outside of the can was charged to + 200 volts, and the leak to a central rod was measured, using a guard ring to avoid conduction over the insulation, which was of the best ebonite.

Both ionization-vessels were made air-tight and fitted with arrangements for testing pressure. One vessel was of brass throughout and had a volume of 7,000 cubic centimeters, while the other of volume 9,000 cubic centimeters was lined with a thin coating of old lead, mixed with as small proportion of tin as would make it adhere successfully to the brass. Both were filled with SO_2 from a siphon where the SO_2 had remained for some considerable time previously, so that there was no radium emanation impurity.

The tilted electroscopes were constructed of thick copper to avoid local differences of temperature, and arrangements were made so that they could be used, if necessary, in a high wind. The author was agreeably surprised to find how robust these instruments are: the electroscopes and attached gold leaves successfully withstood the various journeys, and were carried in a vest pocket.

Camp was made at a height of 4,000 feet on the slopes of Ruapehu, which is a volcanic cone with the same kind of lava rocks from 4,000 feet upwards. At 4,000 feet, according to Kolhörster, there is practically no increase of ionization from sea level. Unfortunately, there was only one clear day on which measurements could be made at the top of the mountain, but on that day a stay of four hours at a height of 9,200 feet was obtained and measurements were made with both electroscopes. Comparative measurements at 4,000 feet were made before and after the ascent. The measurements were converted to ions per c.c. from a knowledge of the combined capacities of the ionization-chambers and electroscopes, which were determined experimentally.

The results obtained on January 24, 1922, were as follows:

Station	Ions per cubic centimeter	
	Brass can, 7,000 c.c. Capacity = 13.1 cm.	Lead lined can, 9,000 c.c. Capacity = 14.8 cm.
Before ascent, 4,000 ft.......	11	18
Mountain top, 9,200 ft......	11.5	19
After ascent, 4,000 ft.......	11.5	18

The measurements at 9,200 feet were only of a little better than eight per cent accuracy, while those at 4,000 feet were somewhat more accurate. The results show that the ionizations at 4,000 feet and 9,200 feet are the same to within one ion per c.c., even when the ionization-vessel is lead-lined and contains sulphur dioxide. Under such conditions, if we accept Kolhörster's result as due to γ rays, there ought to be about 4x3.7, i. e., 15 ions per c.c. difference between the two stations. The author hopes to repeat the experiments and to obtain a greater degree of accuracy.

It may be of interest to note that using similar apparatus to the above in January-February, 1921, at the Apia Observatory, Samoa, variations in ionization were observed at sea level as much as 30 per cent above and below the average. These variations were irregular from day to day and no simple correlation with meteorological conditions was obtained. The matter is being investigated further, both in Apia and Wellington.

In conclusion the author wishes to thank Mr. W. C. Harwood, B. Sc., for his kind and efficient assistance in these experiments.

Victoria University College, Wellington, N. Z.,
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UEBER DIE SELBSTAUFLADUNG KORPUSKULAR STRAHLENDER KOERPER.

VON E. SCHWEIDLER.

[*Summary.*—1. Tbe observed phenomena, which have led to hypotheses regarding the existence of corpuscular cosmic rays, are briefly discussed and the importance is pointed out of deducing the theoretical consequences resulting from the charged state of the emitting cosmic bodies. 2. The characteristics of corpuscular rays are discussed, especially the "radiation potential," P (quotient of the kinetic energy and the electric charge of a particle), and the magnetic deflectibility. 3. The stationary charge of a sphere, which spontaneously emits corpuscular rays into a surrounding vacuum, is computed; it is larger than the product Pa ("radiation potential" times radius of sphere), and increases with intensity of emission; the emitted particles are compelled to turn back at a distance A, the values of which are computed; numerical examples for the Moon, as the supposed source of radiation, are added. 4. The stationary charge during simultaneous spontaneous emission of positive and negative corpuscular rays is computed. 5. Analogous calculations are made on the assumption that a sphere with a strongly ionized surface emits a spontaneous radiation and hence on account of its charging, a compensating field-driven ion-radiation is emitted; in an equilibrium condition, therefore, at a great distance, there exist both positive and negative rays of equal average intensity and equal velocity; the results are applied to the case of the Sun and several numerical examples are given.]

1. EINLEITUNG.

Strahlungen korpuskularer Natur spielen in der kosmischen Physik eine wichtige Rolle. Zunächst sind es die Nordlichterscheinungen, die nach der von Birkeland aufgestellten und insbesondere von Störmer, Lenard und Vegard weiter entwickelten Theorie auf solche Strahlen zurückgeführt werden; ihre quantitativen Merkmale (Ladung, Masse, Geschwindigkeit) sind allerdings bisher nicht mit voller Sicherkeit anzugeben. Während aus der Lage des Gürtels grösster Nordlichthäufigkeit auf Strahlen sehr grosser magnetischer Steifigkeit (also entweder sehr schnelle β-Strahlen oder Strahlen grosser Masse) zu schliessen wäre, deuten die beobachteten räumlichen Verhältnisse (Höhe und vertikale Ausdehnung der Lichterscheinungen) unter Berücksichtigung der Bahnform und der Absorption auf negative Strahlen verhältnismässig geringer Steifigkeit.[1] Diesen Widerspruch sucht bekanntlich Störmer durch die Annahme zu lösen, dass ausserterrestrische ringförmige Ströme—ebenfalls korpuskularer Natur—

[1] C. STÖRMER, *Geofys. Publ.* 1, Nr. 5, Kristiania, 1921.

schon weit ausserhalb der Atmosphäre die Bahnen der ankommenden Teilchen durch ihr magnetisches Feld beeinflussen. Auch die Wirkung der elektrostatischen Abstossungskräfte zwischen den Teilchen eines Schwarmes ist theoretisch noch nicht ganz befriedigend aufgeklärt.

Neben den Nordlichten sind aber noch andere Erscheinungen bekannt, die auf die Existenz kosmischer Korpuskularstrahlen hinweisen. Zunächst ist es die von Gockel und von Hess zuerst beobachtete, in höheren Schichten der Atmosphäre ionisierend wirksame sehr durchdringende Strahlung, die wenigstens indirekt (als von ihnen erzeugte Sekundärstrahlung) auf von aussen kommende Korpuskularstrahlen zurückgeführt werden könnte. Ferner ist aus der Aufrechterhaltung der negativen Erdladung auf eine von aussen kommende, sehr durchdringende negative Korpuskularstrahlung geschlossen worden (Simpson,[2] Swann,[3] Schweidler,[4] Seeliger.[5])

Endlich hat Bauer[6] aus erdmagnetischen Daten die Existenz eines Stromsystems festgestellt, dessen Stromlinien im allgemeinen in den Polarkappen der Erde aus ihrer Oberfläche austreten und im Aequatorialgürtel eintreten. Auch er hält eine Erklärung durch Korpuskularstrahlen für möglich, die dann in niedrigen und mittleren Breiten positive, in hohen Breiten negative Ladungen durch die Erdatmosphäre hindurch transportieren; eventuell wären auch Strahlen entgegengesetzter Ladung und Richtung (also von der Erde ausgehend) denkbar. In jedem Falle wäre ihnen eine ausserordentlich grosse Durchdringungsfähigkeit zuzuschreiben.

Bei allen diesen auf mehr oder minder ausreichenden Beobachtungstatsachen beruhenden und daher in verschiedenem Grade präzisierten Hypothesen erscheint es nun von Interesse, die Konsequenzen zu betrachten, zu denen man in Bezug auf den Ladungszustand der die Strahlen aussendenden Weltkörper gelangt.

2. DIE CHARAKTERISTISCHEN KONSTANTEN KORPUSKULARER STRAHLEN.

Eine sogenannte "homogene" Korpuskularstrahlung ist eindeutig bestimmt durch die Zahl, Masse, Ladung, und Geschwindigkeit der Teilchen. Wir bezeichnen die in der Zeiteinheit (sec) die

[2] G. C. SIMPSON, *Nature*, **69**, 270, 1904.
[3] W. F. G. SWANN, *Terr. Mag.* **20**, 105, 1915.
[4] E. v. SCHWEIDLER, *Wien Ber.* **127**, 515, 1918, und *Ann. d. Phys.* (4) **63**, 726, 1920.
[5] R. SEELIGER, *Ann. d. Phys.* (4) **62**, 446, 1920.
[6] L. A. BAUER, *Terr. Mag.* **25**, 145, 1920.

Flächeneinheit (cm^2) des Querschnittes eines Bündels passierende Teilchenzahl mit z; die Ladung (in statischen Einheiten) mit e; die Masse (in g) oder genauer—in Berücksichtigung der Abhängigkeit der Masse von der Geschwindigkeit—die Ruhmasse mit m; endlich die Geschwindigkeit mit $v = \beta . c$, wobei c die Lichtgeschwindigkeit und β ein zwischen 0 und 1 liegender dimensionsloser Faktor ist.

Für die bei der Lorentz-Transformation auftretende Grösse $\frac{1}{\sqrt{1-\beta^2}}$, führen wir die abkürzende Bezeichnung η ein; die kinetische Energie eines Teilchens ist dann nach den Formeln der speziellen Relativitätstheorie:

$$E = mc^2 \left(\frac{1}{\sqrt{1-\beta^2}} - 1\right) = mc^2 (\eta - 1)$$

was bekanntlich bei kleinen Geschwindigkeiten ($\beta << 1$) in die gewöhnliche Formel $E = \frac{1}{2} mc^2 \beta^2$ übergeht.

Drücken wir E als Produkt Pe einer Spannung P und der Teilchenladung e aus, so bedeutet P diejenige Potentialdifferenz (in *stat.* Einh.), die das ursprünglich ruhende Teilchen in einem beschleunigenden Felde durchlaufen muss, um die Endgeschwindigkeit βc zu erhalten, bezw. die Potentialdifferenz, die bei verzögerter Bewegung das Teilchen von der Anfangsgeschwindigkeit βc, auf die Geschwindigkeit Null abbremst. Wir wollen P, das (in Volt gemessen) gewöhnlich die "Voltgeschwindigkeit" genannt wird, hier kurz das "*Strahlpotential*" nennen und durch $P = \frac{mc^2}{e} (\eta - 1)$ darstellen. Durchläuft ein Teilchen mit dem Strahlpotential P_0 eine beschleunigende oder bremsende Potentialdifferenz Π, so ist am Ende der Bahn sein Strahlpotential $P = P_0 \pm \Pi$. Für die Berechnung der Zeit, die es zu dieser Strecke braucht, ist es von Bedeutung, dass trotz Aenderung der kinetischen Energie die Geschwindigkeit sich nur wenig ändert, falls β_0 sehr gross ist. Durchläuft z. B. ein Teilchen mit $\beta_0 < 0.3$ in einem bremsenden Feld konstanter Stärke bis zum Umkehrpunkt die Strecke l, so ist die Bewegung sehr annähernd eine gleichförmig verzögerte und daher die mittlere Geschwindigkeit $\bar{v} = \frac{1}{2} \beta_0 c$. Ist dagegen z. B. $\beta_0 = 0.9999$ und l bei entsprechend verstärktem Felde ebenso gross wie früher, so ist nach Durchlaufen von 0.98 l die Geschwindigkeit immer noch grösser als 0.9 c, die Bremsung erfolgt rapid im letzten

kleinen Stück der Bahn und die mittlere Geschwindigkeit liegt nur wenige Prozente unter der Anfangsgeschwindigkeit.

Das für das Verhalten in magnetischen Feldern charakteristische Produkt $H\rho$ (in Γ. cm) aus magnetischer Feldstärke und Krümmungsradius ist in unserer Bezeichnungsweise:

$$H\rho = \frac{mc^2}{e} \cdot \eta\beta$$

denn $m\eta$ ist die "transversale Masse" und βc die Geschwindigkeit. Für sehr grosse Geschwindigkeiten (β nahe gleich 1, η gross gegen 1) werden daher die Grössen $H\rho$ und P (in stat. Einh.) einander nahezu gleich. Die numerischen Werte veranschaulicht die folgende Tabelle:

β	η	$(\eta-1)$	$\eta\beta$
0.0	1.000	0.000	0.000
0.1	1.005	0.005	0.100
0.2	1.020	0.020	0.204
0.3	1.048	0.048	0.314
0.4	1.091	0.091	0.436
0.5	1.155	0.155	0.578
0.6	1.250	0.250	0.750
0.7	1.400	0.400	0.980
0.8	1.667	0.667	1.334
0.9	2.294	1.294	2.065
0.95	3.203	2.203	3.043
0.99	7.089	6.089	7.018
0.995	10.01	9.012	9.962
0.999	22.36	21.36	22.34
$1-10^{-4}$	70.71	69.71	70.70
$1-10^{-5}$	223.6	222.6	223.6
$1-10^{-6}$	707.1	706.1	707.1

Für die Berechnung von $P = \frac{mc^2}{e}(\eta - 1)$

und $H\rho = \frac{mc^2}{e}\eta\beta$

gelten die Werte:

$$\frac{mc^2}{e} = 1694 \text{ bei Elektronen}$$
$$= 3.13 \times 10^6 \text{ bei } H\text{-Kernen}$$
$$= 6.21 \times 10^6 \text{ bei } \alpha\text{-Teilchen}$$

und leicht analog zu ermittelnde Werte für positive Atomionen anderer Art.

3. DIE SELBSTAUFLADUNG DURCH SPONTANE KORPUSKULARSTRAHLUNG.

Wir nehmen an, dass eine feste Kugel vom Radius a von absolutem Vakuum ungeben sei und spontan, d. h. ohne Mitwirkung eines elektrischen Feldes, nach Art eines radioaktiven Körpers eine homogene Korpuskularstrahlung (Strahlpotential P_0) aussende. Es sei z die Zahl der Teilchen pro Flächen- und Zeiteinheit, also $I = 4\pi a^2 ze$ der ganze ausgesandte Strom. Der Einfachheit halber setzen wir weiter voraus, dass die Strahlung die Oberfläche überall *senkrecht* verlasse.

Die Kugel nimmt dann eine Ladung entgegengesetzten Vorzeichens an, erzeugt dadurch ein bremsendes Feld und erreicht asymptotisch einen stationären Ladungszustand, bei dem in der Zeiteinheit ebensoviele Teilchen auf die Kugel zurückgetrieben als spontan emittiert werden. Es sei Emission negativer Teilchen und daher positive Aufladung vorausgesetzt; der umgekehrte Fall ist dann natürlich durch Vorzeichenswechsel in den Formeln erledigt. Zunächst—vom ungeladenen Zustand beginnend—gehen die emittierten Teilchen in unendliche Entfernung, solange bis die Kugel eine Ladung im Betrage $P_0\, a$ angenommen hat; sobald dieser Grenzwert überschritten ist, werden alle weiterhin ermittierten Teilchen in endlicher Entfernung A zur Umkehr gebracht und gelangen nach einer gewissen Zeit 2 T (Steigdauer und Falldauer) wieder zurück. Im stationären Zustande ist die Ladung der Kugel $Q_a > P_0 a$, die zwischen $r=a$ und $r=A$ auf dem Hin- oder Rückwege befindilchen Teilchen haben eine Gesamtladung $-Q'$ und es muss die Bedingung erfüllt sein:

$$Q_a - Q' = P_0 a \tag{1}$$

Andererseits muss gelten:

$$Q' = 4\pi a^2 ze\ .\ 2T = I.2T \tag{2}$$

da eben die negative "Teilchenatmosphäre" aus den innerhalb der Zeit $2T$ emittierten Teilchen besteht.

Die stationäre Ladung Q_a, die Umkehrentfernung A und die Steigdauer T sind also abhängig von P_0, a und I. Die Berechnung dieser Grössen und der Feldverteilung im allgemeinen Falle ist ziemlich kompliziert; es seien daher hier nur einige Spezialfälle bahandelt.

Es werde angenommen, dass die Anfangsgeschwindigkeit β_0, klein und daher die Teilchenmasse praktisch konstant sei; ferner dass die Emission I so klein sei, dass das Feld der Raumladung $-Q'$ vernachlässigt werden kann. Dann lässt sich zu jedem vorge-

gebenen Werte der Umkehrentfernung A die zugehörige Ladung Q_a und die Steigdauer T berechnen. Zunächst folgt aus den Potentialwerten $V_a = \frac{Q_a}{a}$ und $V_A = \frac{Q_a}{A} = V_a - P_o$ die Gleichung:

$$Q_a\left(\frac{1}{a} - \frac{1}{A}\right) = P_o = \frac{m\beta^2_o c^2}{2\,e} \tag{3}$$

Ferner folgt aus der für den Fall eines Teilchens im Felde der Ladung Q_a geltenden Differentialgleichung: $m\frac{d^2r}{dt^2} = -e\frac{Q_a}{r^2}$ und aus der Anfangsbedingung, dass $r = A$ und $\frac{dr}{dt} = 0$ für $t = 0$, nach Integration die Gleichung:

$$\frac{r}{A}\sqrt{\frac{A}{r} - 1} + \arctan\sqrt{\frac{A}{r} - 1} = \sqrt{\frac{2Q_a e}{A^3 m}}\cdot t$$

und hieraus für die Falldauer T:

$$T = \sqrt{\frac{A^3 m}{2Q_a e}}\left[\frac{a}{A}\sqrt{\frac{A}{a} - 1} + \arctan\sqrt{\frac{A}{a} - 1}\right] \tag{4a}$$

oder unter Berücksichtigung der Gleichung (3):

$$T = \frac{A}{\beta_o c}\sqrt{\frac{A}{a} - 1}\left[\frac{a}{A}\sqrt{\frac{A}{a} - 1} + \arctan\sqrt{\frac{A}{a} - 1}\right] = \frac{A}{\beta_o c}\cdot f\left(\frac{A}{a}\right) \tag{4b}$$

Numerische Werte der hier auftretenden Funktion $f\left(\frac{A}{a}\right)$ gibt folgende Tabelle:

$\frac{A}{a}$	1	1.25	2	5	10	50	101	401	901	10001
$f\left(\frac{A}{a}\right)$	0	0.432	1.285	3.02	4.65	11.0	15.7	31.4	47.2	158

Vermöge der Gleichungen (1) und (2) ist nun $Q_a = 2\,T\,I + P_o a$, andererseits nach Gleichung (3) $Q_a = P_o a\frac{A}{A-a}$, also

$$2\,I\,T = P_o a\frac{a}{A-a} \tag{5}$$

Es kann somit aus (4*b*) und (5) zu einem vorgegebenen Werte A berechnet werden, welche Emission I dazu nötig ist; die Formel (5) gilt nur, wenn A gross gegen a, da nur dann die Voraussetzung erfüllt ist, dass $-Q'$ vernachlässigt werden kann.

Ein numerisches Beispiel sei das folgende: eine Kugel von der Grösse des Mondes ($a = 1.74\text{x}10^8$ cm, $4\pi a^2 = 38\text{x}10^{16}$ cm^2) sende β-Strahlen mit der Anfangsgeschwindigkeit $\beta_o = 0.3$, Strahlpo-

tential $P_0 = 82$ stat. Einh. aus. Wenn die Umkehrentfernung $A = 401a$ sein soll (also ungefähr doppelt so gross wie die Distanz Mond-Erde), so berechnet sich nach (4*b*) und obiger Tabelle die Steigdauer $T = \frac{6.98 \text{x} 10^{10}}{0.9 \text{ x} 10^{10}} \text{ x } 31.4 = 245$ sec und daraus weiter nach (5) $I = 0.72 \text{x} 10^5 \frac{\text{stat.-Einh.}}{\text{sec}} = 1.5 \text{x} 10^{14} \frac{\text{Elem. quanten}}{\text{sec}}$, bezw. die Zahl $z = 4 \text{x} 10^{-4} \frac{\beta\text{-Strahlen}}{\text{cm}^2. \text{ sec}}$. Für $A = 101a$, also rund die halbe Distanz Mond-Erde, wird analog $T = 30.5$ sec und $I = 0.49 \text{x} 10^{16}$ $\frac{\text{Elem. quanten}}{\text{sec}}$ oder $z = 130 \text{x} 10^{-4} \frac{\beta\text{-Strahlen}}{\text{cm}^2 \text{ sec}}$.

Je höher I, bezw. z wird, um so höher ist Q_a, um so kleiner A und T. Schon bei ganz schwacher β-Strahlung der Mondoberfläche ($0.01 \frac{\beta \text{ Str.}}{\text{cm}^2 \text{ sec}}$) würden die Teilchen die Erde nicht mehr erreichen, wobei der Mond als absolut atmosphärenlos angenommen ist. Zum Vergleich sei bemerkt, dass eine Oberfläche von der Beschaffenheit der Erdrinde etwa $7 \text{x} 10^{-3}$ β-Strahlen pro cm^2 und sec aussendet.

Bei schnellen Strahlen wird allerdings die einer vorgegebenen Entfernung A zugeordnete Steigdauer verkleinert, P_0 vergrössert, also I beträchtlich vergrössert. Es lässt sich aber leicht berechnen, dass selbst bei einer enorm raschen (experimentell nicht bekannten) β-Strahlung mit $\beta_0 = 0.999$, $P_0 = 35500$ stat. Einh. die zu $A = 101a$ gehörige Emission auf das rund 20000 fache des vorigen Beispieles erhöht würde und somit auch in diesem Falle eine β-Strahlung von $200 \frac{\text{Strahlen}}{\text{cm}^2 \text{ sec}}$, was bei radioaktiven Messungen als eine zwar gut messbare, aber immerhin schwache Strahlung bezeichnet würde, nicht mehr die Erde erreichen würde.

Für eine fiktive α-Strahlung mit $\beta_0 = 0.1$, $P_0 = 31000$ ergibt sich durch analoge Rechnung, dass zu $A = 101a$ eine Emission von $z = \frac{\alpha\text{-Strahlen}}{\text{cm}^2 \text{ sec}}$ zugeordnet ist.

Zusammenfassend kann man also sagen, dass bei Körpern von den Dimensionen der Weltkörper schon eine für unsere Beobachtungsmethoden schwache oder höchtens mässige Emission korpuskularer Strahlen durch Aufladung des emittierenden Körpers ein bremsendes elektrisches Feld erzeugt, das die Teilchen schon in relativ geringer Entfernung zur Umkehr zwingt und nicht bis zu benachbarten Weltkörpern kommen lässt. Der emittierende Körper nimmt dabei im stationären Zustande eine Ladung an, die grösser als $P_0 a$ ist. Mit wachsender Stärke der Emission steigt diese Ladung, während die Umkehrentfernung abnimmt.

4. Die Selbstaufladung bei gleichzeitiger spontaner Emission positiver und negativer Strahlung.

Wie früher sei eine Kugel (Radius a) gegeben, die sich in einem Vakuum befindet und gleichzeitig eine positive Strahlung der Gesamtintensität I_1 und eine negative I_2 aussende, wobei $I_2 > I_1$, so dass die Kugel eine positive Ladung annimt. P_0 sei wieder das Strahlpotential der negativen Strahlung.

Unter der (physikalisch nicht realisierbaren) Voraussetzung, dass die negative Strahlung *absolut homogen* sei und die Oberfläche genau senkrecht verlasse, *existiert dann überhaupt kein stationärer Ladungszustand.* Denn ist $Q_a \leqq P_0 a$, so gehen alle Teilchen ins Unendliche und infolge des Ueberwiegens der negativer Emission wächst Q_a über den Betrag $P_0 a$ an. Ist aber $Q_a > P_0 a$, so gelangen schliesslich alle emittierten negativen Teilchen wieder zurück, während die fortgehende positive Strahlung I_1 eine Abnehme von Q_a unter $P_0 a$ bewirkt. Das Resultat wäre ein periodisches Schwanken um den Betrag $P_0 a$.

Nehmen wir aber an, dass die Anfangsgeschwindigkeiten, bezw. Strahlpotentiale der negativen Teilchen nicht absolut gleich, sondern über ein beliebig kleines Intervall P_0 bis $P_0 + \triangle P_0$ verteilt sind, so lässt sich stets ein dazwischen liegenden Wert $\overline{P}$ angegeben, derart dass die Emission aller Teilchen, deren $P > \overline{P}$ ist, den Betrag I_1 annimt und somit die positive Emission kompensiert. $\overline{P}a$ ist dann die stationäre Ladung der Kugel.

5. Die Selbstaufladung eines spontan strahlenden ionisierten Körpers.

Im Gegensatze zu den Voraussetzungen der vorigen Abschnitte sei angenommen, dass der emittierende Körper in seiner Oberflächenschichte eine sehr grosse Zahl freier Elektrizitätsträger (Ionen) enthalte, z. B. ein glühender Gasball wie die Sonne oder ein fester Körper mit stark ionisierter Atmosphäre wie die Erde sei.

Wie nehmen ferner wieder eine spontane, negative, senkrecht austretende homogene Korpuskularstrahlung vom Strahlpotential P_0 und der Gesamtstärke I an. Das von der Selbstaufladung erzeugte Feld treibt die in der Oberfläche ruhenden positiven Ionen nach aussen und es tritt ein stationärer Zustand ein, sobald der Ionenstrom die spontane Emission kompensiert. Die Berechnung des dazu nötigen Feldes erfordert die Lösung eines Problems, das man als Ermittlung des "*Raumladungsgrenzstromes im Vakuum*

zwischen konzentrischen Kugelflächen" bezeichnen kann. Analoge Probleme, die sich aber auf den Grenzstrom zwischen parallelen ebenen Platten oder zwischen konzentrischen Zylinderflächen beziehen, wurden von Langmuir[7] und von Schottky[8] gelöst.

Es werde also zunächst die folgende Aufgabe behandelt: Gegeben ist eine Kugel mit stark ionisierter Oberfläche und dem Radius a innerhalb einer leitenden konzentrischen Hohlkugel mit dem Radius A; zwischen beiden sei Vakuum. Wenn die innere Kugel auf dem Potential Null, die äussere auf dem konstanten Potentiale $-V_A$ gehalten wird, geht ein strom positiver Ionen von innen nach aussen, dessen Stärke I zu berechnen ist.

Unter der Voraussetzung, dass die Endgeschwindigkeit der positiven Ionen (Masse m, Ladung e) nach Durchlaufen der Potentialdifferenz V_A immer noch klein gegen die Lichtgeschwindigkeit sei, gilt nach Langmuir (*l. c.*):

a. Zwischen *ebenen Platten* in der Distanz A ist bei der Spannung V_A die Stromdichte

$$i = \frac{1}{9\pi}\sqrt{\frac{2e}{m}} \cdot \frac{V_A^{\frac{3}{2}}}{A^2}$$

b. Zwischen *konzentrischen Zylindern* (Radien a und A) ist der Strom pro Längeneinheit:

$$j = \frac{2}{9}\sqrt{\frac{2e}{m}} \cdot \frac{V_A^{\frac{3}{2}}}{A\phi(\frac{A}{a})}$$

wobei ϕ eine durch eine unendliche Reihe darstellbare Funktion ist, die bei wachsendem Argument sich rasch dem Grenzwert 1 nähert.

c. Schliesslich beweist Langmuir, dass auch bei *beliebig gestalteten Elektroden* der Gesamtstrom I proportional zu $V_A^{\frac{3}{2}}$ ist.

Es bleibt also für den hier vorliegenden Fall noch die Abhängigkeit des I von a and A zu bestimmen.

In diesem Falle gilt für eine Entfernung r, in der das Potential den Wert $-V(r)$ hat

$$\frac{mv^2}{2} = e\,V(r) \tag{6}$$

Eine zweite Gleichung erhalten wir aus der Kontinuitätsbedingung, dass das Produkt aus der Ladung einer Kugelschale, die von r bis $r + dr$ reicht, und der dort vorhandenen Ionengeschwindigkeit v den konstanten Wert Idr haben muss. Da nun die Feld-

[7] I. Langmuir, *Phys. Rev.* (2) **2**, 450, 1913; *Phys. Zeitschr.* **15**, 348 u. 516, 1914.
[8] W. Schottky, *Phys. Zeitschr.* **15**, 526, 1914.

stärke, durch $\frac{dV}{dr}$, die gesamte innerhalb r befindliche Ladung durch $r^2 \frac{dV}{dr}$ und somit die Ladung der Kugelschale durch $d[r^2 \frac{dV}{dr}]$ gegeben ist, folgt:

$$v \frac{d}{dr} [r^2 \frac{dV}{dr}] = I \tag{7}$$

und unter Berücksichtigung der Gleichung (6) weiter

$$\sqrt{V} \frac{d}{dr} [r^2 \frac{dV}{dr}] = \sqrt{\frac{m}{2e}} . I = K \tag{8}$$

Durch die Substitution von neuen Variablen

$$\xi = \log \text{nat} \frac{r}{a} \text{ und } \psi = V^{3/4}$$

geht die Differentialgleichung (8) über in

$$12\psi \frac{d^2\psi}{d\xi^2} + 4 \left(\frac{d\psi}{d\xi}\right)^2 + 12\psi \frac{d\psi}{d\xi} = 9K \tag{9}$$

Die Darstellung von ψ durch eine Potenzreihe und zwar unter Berücksichtigung der Anfangsbedingung, dass für $r = a$ oder $\xi = 0$; $V = 0$ und daher $\psi = 0$ ist, in der Form $\psi = \alpha_1\xi + \alpha_2\xi^2 + \ldots\ldots = \alpha_1 \xi \left[1 + \frac{\alpha_2}{\alpha_1} \xi + \frac{\alpha_3}{\alpha_4} \xi^2 + \ldots\ldots\right]$ liefert dann aus Gleichung (9) für die Werte der Koeffizienten:

$$\alpha_1 = \tfrac{3}{2} \sqrt{K};\ \alpha_2 = -\tfrac{3}{10}\, \alpha_1;\ \alpha_3 = \tfrac{9}{50}\, \alpha_1;\ \alpha_4 = -\tfrac{36}{1000}\, \alpha_1; \ldots.$$

und somit die Gleichung

$$\psi = V^{3/4} = \tfrac{3}{2} \sqrt{K} \log \text{nat} \tfrac{r}{a} [1 - \tfrac{3}{10} \log + \tfrac{18}{100} \log^2 - \tfrac{36}{1000} \log^3 + \ldots.] \tag{10}$$

oder

$$V_A = \left(\frac{3}{2}\right)^{\frac{4}{3}} \left(\frac{m}{2e}\right)^{\frac{1}{3}} I^{\frac{2}{3}} \left(\log \text{nat} \frac{A}{a}\right)^{\frac{4}{3}} \left[1 - \frac{3}{10} \log + \ldots\ldots\right]^{\frac{4}{3}} \tag{10a}$$

beziehungsweise:

$$I = \tfrac{4}{9} \sqrt{\frac{2e}{m}} \frac{V_A{}^{\frac{3}{2}}}{\left(\log \text{nat} \frac{A}{a}\right)^2 \left[1 - \frac{3}{10} \log + \ldots\ldots\right]^2} \tag{10b}$$

Bei wachsender Entfernung der Elektroden steigt also die zur Erziehung eines gegebenen Stromes I notwendige Spannung V_A ebenso wie bei den von Langmuir behandelten Fällen ins Unendliche und zwar hier logarithmisch mit A. Von einer geladenen ionisierten Kugel wäre also bei endlicher Spannung überhaupt kein endlicher stationärer Strom in den umgebenden unendlichen Raum zu erzielen, im Gegensatz z. B. zu einer geladenen Kugel in

einem unendlich ausgedehnten nach dem Ohm'schen Gesetze leitenden Medium. Aber diese Unmöglichkeit beruht auf der Wirkung der Raumladung und fällt weg, wenn in hinreichender Entfernung die positive Raumladung der abströmenden Ionen durch eine negative Raumladung kompensiert wird.

Dies ist der Fall bei dem von uns ursprünglich betrachteten Vorgang, wo die ionisierte Kugel gleichzeitig eine negative Emission I besitzt. Im stationären Zustand tritt dann folgende Feldverteilung ein: die Kugel lädt sich auf ein positives Potential Π auf; für $r > a$ nimmt $V(r)$ zunächst langsam, dann rasch, dann nach Ueberschreitung eines Wendepunktes wieder langsamer auf den Wert Null in $r = \infty$ ab; die Raumdichte ist überall positiv und sinkt mit wachsenden r asymptotisch und zwar rascher als $\frac{1}{r^2}$ abnehmend auf Null. Die Bedingung hierfür ist, dass für grosse Werte von r die *Geschwindigkeiten* der spontan emittierten negativen Teilchen und der durch das Feld beschleunigten positiven Ionen *gleich* werden, da sowohl die Raumdichten als auch die Stromdichten (Produkte aus Raumdichte und Geschwindigkeit) gleich sein sollen.

Nun ist in grosser Entfernung für die spontane negative Strahlung mit dem ursprünglichen Strahlpotential $P_\circ$ infolge der Verzögerung $P_\infty = P_\circ - \Pi$, während die feldgetriebenen positiven Ionen schliesslich ein Strahlpotential Π erhalten.

Beziehen wir daher den Index 1 auf die spontan emittierten Teilchen, den Index 2 auf die feldgetriebenen Ionen, so gilt nach den im Abschnitt (2) angeführten Beziehungen:

$P_\circ - \Pi = \frac{m_1 c^2}{e_1} \ (\eta_1 - 1)$ und $\Pi = \frac{m_2 c^2}{e_2} \ (\eta_2 - 1)$ und somit, da für $r = \infty : \beta_1 = \beta_2$ und daher auch $\eta_1 = \eta_2$, die Gleichung

$$\frac{P_\circ - \Pi}{\Pi} = \frac{m_1 e_2}{m_2 e_1} \text{ oder } \Pi = P_\circ \frac{m_2\, e_1}{m_2\, e_1 + m_1\, e_2} \tag{11}$$

Diese Gleichung (11) muss auch dann erfüllt sein, wenn die anfänglich—zur Berechnung von (10)—vorausgesetzte Bedingung, dass die Endgeschwindigkeit $\beta_2 c$ für $r = \infty$ klein gegen die Lichtgeschwindigkeit sei, *nicht mehr* erfüllt ist. Nur die Feldverteilung in der Umgebung der emittierenden Kugel wird dann verändert, derart dass das Gebiet merklicher Raumdichte sich weiter hinaus erstreckt.

Einsetzen numerischer Werte zeigt, dass bei spontaner *Elektronenstrahlung* (β-Strahlung) und *H-Ionen* als Trägern der feldgetriebenen Strahlung $e_2 = e_1$, $m_2 = 1848\ m_1$, also $\Pi = \frac{1848}{1849} P_0$ wird. Umgekehrt wäre bei spontaner *H*-Strahlung und feldgetriebener Kathoden- (Elektronen-) Strahlung dann $\Pi = \frac{1}{1849} P_0$ und analog bei spontaner α-Strahlung $\Pi = \frac{1}{3669} P_0$.

Bei *Anwendung auf die Sonne* ergibt sich daraus das bemerkenswerte Resultat: ob man nun von der Birkeland-Störmer'schen Hypothese einer spontanen *Elektronen-emission* der Sonne ausgeht oder, der ursprünglichen Auffassung Vegard's folgend, eine spontane *positive Strahlung* annimmt, in jedem Falle müssen im stationären Zustand in grosser Entfernung beide Strahlengattungen vorhanden sein und zwar mit gleicher mittlerer Intensität und mit gleicher Teilchengeschwindigkeit, so dass entsprechend der grösseren Masse die positive Strahlung eine grössere magnetische Steifigkeit und Durchdringungsfähigkeit besitzt als die negative.

Bekanntlich wurde in mässigen Breiten (Deutschland, England) häufig—ohne jeden Zusammenhang mit ausgesprochenen Nordlichterscheinungen oder magnetischen Störungen—mittels hinreichend lichtstarker Spektroskope die Nordlichtlinie im Lichte des nächtlichen Himmels beobachtet (Wiechert, Rayleigh) und daraus manchmal auf ein allerdings schwaches aber permanentes Nordlicht viel grösserer räumlicher Verbreitung geschlossen. Bei der gewöhnlichen Auffassung ist es eigentlich nicht recht verständlich, warum die magnetisch steife, aber schwache Strahlung so häufig, dagegen die stark ablenkbare intensive Strahlung, welche die Nordlichter im gewöhnlichen Sinne des Wortes erzeugt, seltener ist. Diese Tatsache wird verständlich, wenn wir annehmen, dass fast immer von irgend welchen "aktiven" Stellen der Sonne Bündel spontaner negativer Strahlung ausgehen, aber nur bei günstiger Konstellation die Erde treffen und dann infolge ihrer geringen Steifigkeit hauptsächlich in den Polargegenden intensive Lichterscheinungen hervorrufen; dass aber die feldgetriebene positive Strahlung (in erster Linie wohl *H*-Kerne) *gleichmässig*, also mit geringerer Stromdichte, von der *ganzen* Sonnenoberfläche emittiert wird, daher immer zur Erde gelangt und dann bei ihrer grösseren Steifigkeit schwache, jedoch bis in niedere Breiten reichende Lichterscheinungen in der Atmosphäre erzeugt. Auch als Erreger einer sekundären γ-Strahlung (sehr durchdringenden Strahlung in der Atmosphäre) käme sie eventuell in Betracht.

Ferner ist zu berücksichtigen, dass von der Sonne ausgehende

Bündel spontaner Strahlen unter günstigen Umständen im Magnetfelde eines Planeten abgelenkt und dann durch die elektrostatischen Kräfte zur entgegengesetzt geladenen Sonne zurückgetrieben werden können; hierdurch wird die Ladungsbilanz der Sonne gestört und die Emission der feldgetriebenen Strahlen verändert. Die vielfach vermuteten "*Reflexwirkungen*"[9] der Planeten, die sich in Periodizitäten der Sonnenaktivität äussern, welche mit den Perioden der Planeten übereinstimmen, würden so einer physikalischen Erklärung näher gerückt.

Schliesslich seien noch einige numerische Resultate abgeleitet. Aus den direkt beobachteten Daten schliesst Störmer[10] bei den häufigsten Nordlichtformen auf eine erregende negative Strahlung, bei der das Produkt $H\rho$ von der Grössenordnung 700Γ. cm ist. Entsprechend der Tabelle in Abschnitt 2 folgt daraus abgerundet ein Wert $\beta=0.4$ und $\mathrm{P}=80$ stat. Einh. Nehmen wir H-Kerne als hauptsächliche Träger der feldgetriebenen positiven Strahlung an, so folgt aus $\beta=0.4$ der Wert $\Pi=280000$ stat. Einh. und nach Gleichung (11) P_0 nahezu gleich gross. Aus P_0 berechnet sich, dass die Anfangsgeschwindigkeit der spontanen Strahlen zwischen $(1-10^{-4})$ und $(1-10^{-5})$ liegt. Für die positiven Strahlen hat bei $\beta=0.4$ das Produkt $H\rho$ den Wert $1.3\text{x}10^6\Gamma$. cm. Die positive Sonnenladung wird $Q_a=\Pi_a=$ rund $2\text{x}10^{16}$ stat. Einh. $=4\text{x}10^{25}$ Elementarquanten ($a=7\text{x}10^{10}$ cm gesetzt).

Man kann noch fragen, in welcher Zeit nach Beginn der Spontanstrahlung der stationäre Zustand praktisch erreicht wird. Ohne Kompensation durch positive Strahlen wäre die Endladung in der Zeit $\tau = \dfrac{Q_a}{I_1}$ erreicht; bei einer der vorhandenen Ladung *proportionalen* Ionenemission wäre $Q(t) = Q_a(1 - e^{-\frac{t}{\tau}})$, also z. B. $Q(t) = 0.95\, Q_a$ für $t=3\tau$. Tatsächlich erfolgt die Ionenemission nach Formel (10*b*) proportionel zu $V^{\frac{3}{2}}$, bezw. $Q^{\frac{3}{2}}$, ist also kleiner als eben angenommen. Die Zeit, nach welcher 95% der Endladung erreicht werden, ist daher grösser als τ, kleiner als 3τ, somit von der Grössenordnung 2τ. Soll dies z. B. in rund 22 Stunden $=80000$ sec erreicht werden, so muss $I = \dfrac{4\text{x}10^{25}\ \text{Elementarquanten}}{4\text{x}10^4\ \ \text{Sekunden}} = 10^{21}$ sein. Dem entspricht eine Emission von nur $\frac{1}{60}$ pro cm^2 und sec für die positiven Ionen und von 17 β-Strahlen pro cm^2 und sec für die spontane Strahlung, falls 1 Promille der Sonnenoberfläche als "aktiv" angenommen wird. Bei stärkerer Emission erfolgt die Herstellung des stationären Zustandes entsprechend rascher.

[9]Vergl. insbesondere L. A. BAUER, *Terr. Mag.*, **26**, 1921, pp. 40, 65-66, und 113-115.

[10]C. STÖRMER, *Geofys. Publ.* **1**, Nr. 5, Kristiania, 1921.

ZUSAMMENFASSUNG.

1. Es werden kurz die beobachteten Erscheinungen besprochen, die zu Hypothesen über die Existenz von korpuskularen kosmischen Strahlungen geführt haben, und die Wichtigkeit betont, die theoretischen Konsequenzen bezüglich des *Ladungszustandes* der emittierenden Weltkörper abzuleiten

2. Die Bestimmungsmerkmale korpuskularer Strahlen werden besprochen, speziell das "*Strahlpotential*" P, das als Quotient der kinetischen Energie und der elektrischen Ladung eines Teilchens definiert ist, sowie die *magnetische Ablenkbarkeit*. Eine Tabelle zur Berechnung dieser Grössen bei verschiedenen Geschwindigkeiten ist beigefügt.

3. Die stationäre Ladung einer Kugel, die spontan Korpuskularstrahlen ins umgebende Vakuum aussendet, wird berechnet. Sie ist *grösser* als das Produkt Pa aus Strahlpotential P und Kugelradius a und steigt mit der Intensität der Emission an. Die emittierten Teilchen werden dabei in einer Entfernung A zur Umkehr gebracht; der Wert von A wird ebenfalls berechnet. Numerische Beispiele für den Mond als supponierte Strahlenquelle werden beigefügt.

4. Die stationäre Ladung bei gleichzeitiger spontaner Emission von positiven und negativen Korpuskularstrahlen wird berechnet.

5. Analoge Rechnungen werden durchgeführt unter der Annahme, dass eine in der Oberfläche stark *ionisierte* Kugel eine spontane Strahlung und daher infolge ihrer Aufladung eine kompensierende feldgetriebene Ionenstrahlung aussende. Im stationären Zustande sind in grosser Entfernung dann *positive und negative* Strahlen von *gleicher* mittlerer *Intensität* und *gleicher Geschwindigkeit* vorhanden.

Die Resultate werden auf die Verhältnisse bei der *Sonne* angewendet und einige numerische Beispiele berechnet.

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ON THE SECULAR VARIATION OF THE MAGNETIC DECLINATION IN EKATERINBURG AND SIBERIA.

By Robert Abels, *Physicist at the Ekaterinburg Observatory*.

Using as a basis the magnetic observations made by Dr. A. Smirnow in 1900, 1901, and 1909, and those in 1916, by the author of the present paper, as well as the observations at the Ekaterinburg Observatory, it is found that the magnetic needle reached recently in Siberia its maximum eastern declination and that it has begun its reverse movement towards the west.

At Ekaterinburg, the north end of the needle, since 1761, when the first determinations were made, until the year 1916, has moved constantly towards the east with a mean annual change of about four minutes. In 1761 the value of the declination was 0°50′E; in 1916, 11°03.′8 E. For the year 1917, however, the annual mean value as obtained from the hourly observations at the Observatory, amounted to 11°03.′7 E and for 1918, 11°03.′4 E. Accordingly, the needle remained stationary during 1916-1917, and in the following year moved 0.′3 towards the west. It may be expected, therefore, that it will now continue to move toward the west.[1]

The reverse movement of the magnetic needle began earlier in Siberia than at Ekaterinburg, as may be seen from the following data. Among the points at which the author made observations in 1916, there were four at which Smirnow had observed in 1901. These values, together with those obtained at Ekaterinburg, afford the following comparison:

Table 1

Station	*Easterly Declination* 1901.5	1916.5	*Annual Change*
	° ′	° ′	′
Ekaterinburg	10 08. 6	11 03. 8	3. 7 E.
Petropavlovsk	12 26. 0	13 00. 1	2. 3 E.
Tartarskaja	12 06. 7	12 25. 8	1. 3 E.
Narym[2]	14 31. 7	14 47. 0	1. 0 E.
Mariinsk	11 16. 0	11 02. 7	0. 9 W.

The magnetic needle, accordingly, during the period 1901-1916, or for the epoch 1909, moved, in general, towards the east, though with varying speed. In the west the movement was more rapid than in the east. At Mariinsk, however, where the movement of the magnetic needle was likewise previously easterly, the westerly movement began about 1909. There must, consequently, have been a point between Tatarskaja and Mariinsk, where the needle

[1] The mean annual value of the declination at the Observatory for 1919 was 11°02.′8; for 1920 11°01.′9, and for 1921, 11°01.′5.

[2] Smirnow observed at Narym in 1900, and found the declination to be 14°30.′7 E; one minute has been added to his value to refer it to the year 1901.

stood still in the epoch referred to. By interpolation, the geographic coordinates of this place are found to be $\phi = 55°.8$ N; $\lambda = 82°.9$ E of Gr. There must also have been such a point on the line joining Mariinsk and Narym, probably about 57°.5 N and 84°.8 E.

That the declination was easterly at Mariinsk before 1909 is clear from D. A. Smirnow's paper, entitled "Die magnetischen Elemente auf der Linie von Warschau bis Vladivostok nach den Beobachtungen von 1901, 1904, und 1909." (Bulletin de l'Académie Impériale des Sciences de St.-Pétersbourg, 1910). On the last page of this work Smirnow compares the observations which he made at the same stations in 1901.5 and 1909.5. From these data are obtained the following annual changes which may be considered as applying to the epoch 1905.5:

TABLE 2

Station	*Annual change of declination 1905.5 (1901.5-1909.5)*
	′
Ekaterinburg.......	4. 5 E.
Petropavlovsk.......	3. 5 E.
Tomsk.............	2. 6 E.
Krasnojarsk........	0. 9 E.
Irkutsk............	1. 5 W.

This table gives a representation of the secular change in declination, similar to that shown in the foregoing table. Here also the change in declination is greater in the west than in the east. There is a difference, however, in that the place at which the needle stood still in the year 1905 was between Krasnojarsk and Irkutsk, that is, farther towards the east, than in 1909. By interpolation, we obtain for this place the coordinates, $\phi = 54°.6$ N.; $\lambda = 97°.2$ E.

We have found, then, that the magnetic needle ceased its easterly movement in 1905.5 at $\phi = 54°.6$ N and $\lambda = 97°.2$ E; in 1909.0 at $\phi = 55°.8$ N and $\lambda = 82°.9$ E and at $\phi = 57°.5$ N and $\lambda = 84°.8$ E, and in 1917.0 at $\phi = 56°.8$ N and $\lambda = 60°.6$ E.

The positions, at which the magnetic needle came to a stop, have accordingly moved gradually from east to west. The rate of this movement as obtained from the data for 1905.5 and 1917.0 is 3.2 degrees of longitude per year.

From the data for the year 1909, in combination with those for 1905, the annual motion is 4°.2 and 3°.7, while in combination with those for 1917, 2°.8 and 3°.0, respectively. In round numbers, then, the annual retrograde movement of the magnetic needle has amounted to 3 degrees of longitude.

In the application of this value it must be noted that it is perhaps dependent on geographical latitude, a fact which seems to be indicated by the two values for 1909. At any rate, there can be no doubt but that the magnetic needle will soon assume also in Europe, a westerly motion, just as is at present the case from Irkutsk to Ekaterinburg.

PROVISIONAL SUN-SPOT NUMBERS FOR JANUARY TO JUNE, 1922.

Day	Jan.	Feb.	Mar.	Apr.	May	Jun.
1	..	0	109	26	38	7
2	0	12	127	29	31	0
3	0?	0	122	..	27	0
4	7	..	118	18	..	0
5	..	..	119	17	12	0
6	..	17	112	19	13	0
7	28	42	108	15	10	8
8	..	31	..	7	10	7
9	..	28	..	..	7	7
10	26	34	..	0	0	0
11	22	51	88	0	0	..
12	24	75	97	0	0	23
13	8?	63	79	0	..	17
14	14	39	53	0	0	16
15	..	26	28	0	0	16
16	17	..	16	..	0	10
17	..	13	16	..	0	9
18	7	10	18	..	0	..
19	..	16	11	0	0	0
20	..	7	0	0	0	0
21	..	8	..	..	0	9
22	..	..	..	7	0	7
23	..	8	..	10	0	7
24	0	17	..	17	7	7
25	..	24	38	25	8	7
26	0	36	27?	..	7	..
27	..	..	32	..	9	0
28	..	84	34	14	7	0
29	0	..	32	15	8	0
30	0	..	28	31	13	0
31	..	..	28	..	16	..
Means	10 2	27.9	60.0	11.4	7.7	5.8

A. Wolfer.

[1] For previous table, see *Terr. Mag.*, **26**, 135-136, 1921.

THE MAGNETIC CHARACTER OF THE YEAR 1921

The annual review of the "Caractère magnétique de chaque jour" for 1921 has been drawn up in the same manner as the preceding years. Forty observatories contributed to the quarterly reviews, 38 of them having sent complete data.

Table II of the annual review, containing the mean character of each day and each month, the list of "calm days" and the days recommended for reproduction, is reprinted here.[1]

G. van Dijk.

1921 Table Showing the Magnetic Character for the Year 1921

Dates	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Mean
January	0.9	0.2	0.3	0.8	0.7	0.3	0.4	0.2	0.8	1.0	0.3	0.6	0.1	0.2	0.8	0.7	1.4	0.7	0.4	0.7	0.6	0.2	0.3	0.9	0.3	0.7	0.3	0.4	0.3	0.2	0.8	0.54
February	0.9	0.9	0.2	0.4	1.2	0.9	0.4	0.1	0.1	0.3	0.3	0.1	0.9	0.8	0.2	0.1	0.8	0.5	0.9	0.6	0.8	0.4	0.1	0.3	0.4	0.4	0.4	0.8				0.51
March	1.0	0.9	0.6	0.3	0.1	0.2	0.3	0.1	0.9	1.0	0.3	0.6	0.2	0.9	1.3	1.0	0.2	0.3	0.1	0.1	1.4	1.3	0.3	0.9	1.3	1.2	1.3	0.7	1.2	0.8	0.2	0.68
April	0.2	0.1	0.8	0.1	0.1	0.3	0.1	0.6	0.8	0.8	0.6	1.2	1.6	1.0	0.8	0.6	0.4	1.4	1.2	1.0	1.2	0.9	0.8	0.4	0.3	0.1	0.1	0.6	1.7	0.5		0.67
May	0.4	0.2	0.8	0.8	0.0	0.1	0.0	0.6	0.9	0.7	0.4	1.4	1.9	2.0	2.0	2.0	1.6	0.9	1.6	1.8	1.3	0.8	0.6	0.3	0.1	0.4	0.6	0.8	0.6	0.1	0.2	0.83
June	0.5	0.4	0.8	1.0	0.1	1.1	0.8	1.2	1.0	0.9	0.4	0.2	0.4	0.9	0.2	0.4	0.6	0.1	0.2	0.6	0.4	0.8	0.9	0.4	0.1	0.7	0.3	0.3	0.7	0.3		0.55
July	0.5	0.1	0.2	0.7	0.1	0.7	1.0	1.0	1.2	0.4	0.1	0.5	0.7	0.7	0.9	1.0	0.3	0.3	0.7	0.6	0.1	0.6	0.8	0.4	0.1	0.6	0.4	0.6	0.7	0.7	0.2	0.54
August	0.0	0.7	1.2	0.9	1.1	1.1	0.8	0.7	0.2	0.3	1.0	0.5	0.2	0.6	1.0	1.0	0.7	0.1	0.1	0.3	0.5	0.2	0.1	0.2	0.0	1.1	0.9	0.2	0.0	1.2	0.8	0.58
September	0.2	1.8	0.7	0.8	0.4	0.1	0.7	1.1	0.6	0.3	0.1	0.0	0.1	0.2	0.4	0.6	0.2	0.5	0.6	0.1	0.5	0.2	1.1	0.0	0.0	0.0	0.2	1.4	1.5	0.7		0.50
October	0.9	0.3	0.2	0.8	1.0	0.8	1.0	1.9	1.0	0.6	1.4	1.1	0.2	0.5	0.6	0.1	0.1	0.1	0.1	0.4	1.1	0.6	0.4	0.5	0.2	0.2	1.0	0.9	0.8	0.2	0.9	0.63
November	0.7	0.0	0.1	0.0	1.0	1.3	0.7	0.7	0.7	1.0	0.1	0.2	0.8	0.7	0.4	1.6	1.7	1.2	1.0	0.5	0.8	0.7	1.1	0.5	0.4	0.2	0.1	0.3	0.0	0.1		0.62
December	0.2	0.7	0.7	0.3	0.1	0.0	0.0	0.2	0.3	0.6	0.8	1.4	1.6	0.8	0.6	1.3	1.0	0.5	0.1	0.0	0.0	0.9	1.0	0.7	0.1	0.8	0.9	1.7	1.3	0.8	0.4	0.65

Calm Days

January	2,	8,	13,	14,	22.	February	8,	9,	12,	16,	23.	March	5,	8,	17,	19,	20.
April	4,	5,	7,	26,	27.	May	5,	6,	7,	25,	30.	June	5,	15,	18,	19,	25.
July	2,	11,	18,	21,	25.	August	1,	9,	23,	25,	29.	September	11,	12,	13,	24,	25.
October	3,	16,	17,	18,	19.	November	2,	3,	4,	27,	29.	December	6,	7,	19,	20,	21.

Days Recommended for Reproduction

**May 13; May 15.

*March 21; April 29; May 14; May 16; September 2; November 17.

[1] For previous table, namely for 1920, see *Terr. Mag.*, **26**, 33, 1921.

PERIODICITY OF ACTIVITY IN TERRESTRIAL MAGNETISM.

Having been myself recently engaged in a discussion[1] of the 27-day "period" in magnetic disturbance, I read with interest Dr. G. Angenheister's paper on "Periodicity" in your recent issue.[2] With some of his conclusions my own investigations are in harmony, but others of his conclusions seem to me hardly warranted by the facts. I shall presently explain my reasons for dissent, employing for the purpose the data in the accompanying table, but a few preliminary remarks are desirable on the nature of the international "character" figures of which Dr. Angenheister and I have both made considerable use in our investigations.

As is, I think, well known to all who have considered these figures closely that while they discriminate admirably between the days of a single month, they suffer from the drawback that the significance possessed by the same numeral in different seasons is not the same. In a quiet year the figure 1.8, for example, connotes usually less disturbance than it does in a disturbed year. The years 1911-14, which contain a number of the "great" storms in Angenheister's Tables 1 and 2, *l. c.* pp. 64, 65, were, on the whole, very quiet years, and some of the storms of those years to which "character" figures of 1.8 or 1.9 were assigned were quite ordinary storms.

Another important point is that the international day commences at Greenwich midnight, and—at least in Europe—the Greenwich night hours are much more disturbed than the day hours. In most cases, even of short storms, the morning hours of the second day are highly disturbed, as well as the evening hours of the first day. It follows that in most cases high "character" figures are not isolated, but occur on two and sometimes more successive days. The higher of the successive "character" figures will presumably, as a rule, fall to the day which contains the C. G. of the disturbance; but even if such were always the case it would not tell us whether the height of the disturbance occurred in the morning or the evening. Supposing the first of two storms to culminate in the morning hours of day n, while the second storm culminates in the evening hours of day $n+26$, we get an apparent 26-day interval; while if the first storm culminates in the evening hours of day n, and the second in the morning hours of day $n+28$, the apparent interval is 28 days. In both cases, if we were able to fix the period of culmination, we might obtain 27 days for the interval. Thus the interval between successive storms of a series *may be* decidedly less variable than might be inferred from a study of the international "character" figures. Similar considerations apply to the intervals which Dr. Angenheister obtains when he uses the times of commencement of storms, as was in fact done in Mr.

[1]*Roy. Soc. Proc.* A., Vol. 101, p. 368.

[2]*Terrestrial Magnetism*, Vol. 27, p. 57.

Maunder's papers, which did so much to establish the 27-day "period." It is only when storms possess "sudden commencements" (or Sc's) that a very exact commencing time can be assigned, and even then the length of the storm, and the interval from the Sc to the principal movements, are very variable.

The conclusions drawn by Angenheister to which I here take exception are that there is an essential difference between greater and smaller storms, and that the 27-day period is confined to the latter, while "the greater magnetic storms, character 1.8-2.0, are repeated after integer multiples of 30 days" (*l. c.* p. 79).

A preliminary point to notice is that of the storms which Angenheister takes as the first of two series, A and B, showing the 30-day period, only one—the storm of September 25, 1909—was really outstanding. The storm of September 30, 1909, originating series A, was a comparatively commonplace one. Yet the "character" figures of the subsequent members of the two series appear closely similar. Coming now to the accompanying table, it embodies evidence—to which much could be added—that there is no fundamental difference between Angenheister's greater and lesser storms. It contains sequences[1] of storms in which the 27-day "period" seems clearly indicated, amongst which appear a number of the "great" storms included in Angenheister's Tables 1 and 2. The last two figures of the year follow the date of the month, Aug. 29 (09), for example, signifying August 29, 1909. When these figures are omitted, the year is the same as for the previous storm. The second column gives the international "character" figure, and the third column the interval between the storm given in the same line and the previous storm of the series. Only intervals of from 26 to 28 days are included.

The last two cases in the table were not considered by Angenheister. They are included to show that even a day of the extreme international figure 2.0 can be a member of a 27-day sequence. It may be explained that the mean "character" figure for a month averages about 0.6, and that "character" 1.3 implies very considerable disturbance in all months.

Some doubt may be entertained whether the disturbance of September 30, 1909,—the fundamental disturbance of Angenheister's series A—was a member of a 27-day series; but there seems no reasonable doubt of this in the case of the storm of September 25, 1909, and the other "great" storms of Angenheister which appear in my table. The dates of these Angenheister storms are in Italics. It will be seen that two of the sequences in my table each include two of Angenheister's "great" storms, and that these storms may occupy any position from first to last in the sequence. As a matter of fact, a considerable majority of the "great" storms in Tables 1 and 2 can be arranged as members of ordinary 27-day sequences. Under these circumstances it seems very improbable

[1]The possibility of "accident" playing a part in all such sequences must be conceded.

that there can be any essential difference in the place of origin of the greater and lesser storms such as Angenheister supposes.

To me a most surprising thing is that Angenheister seems really to have recognized himself that some of his "great" storms were members of 27-day sequences, because he can hardly have failed to notice the identity of several of the storms in his Tables 1 and 2 with storms which he gives in his Table 7, p. 71, which is apparently intended to illustrate the existence of the 27-day "period" in what he calls "the small storms" discussed in his Section F. The dates in my table and Angenheister's Table 7 do not always appear identical, but that arises from Angenheister's having used in that table the times of commencement as given in the Porto Rico list.

Whilst large storms are often members of apparent 27-day sequences, I do not recall an instance in which a really outstanding storm such as those of September 25, 1909, and May 14-15, 1921, was followed after a 27-day (or 30-day) interval by a storm of like magnitude. C. CHREE.

TABLE 1.

Date	"Character"	Interval (Days)	Date	"Character"	Interval (Days)	Date	"Character"	Interval (Days)
Aug. 29 (09).	1.4		*Sept. 17 (12)*.	1.8		Mch. 3 (16)..	1.2	
Sept. 25.....	2.0	27	Oct. 14......	1.6	27	Mch. 29.....	1.7	26
Oct. 23......	1.7	28	Nov. 10.....	1.2	27	*Apr. 25*.....	1.9	27
			Dec. 7......	1.4	27	May 22.....	1.7	27
Sept. 3 (09)..	1.2		Jan. 3 (13)...	1.4	27			
Sept. 30.....	1.8	27	Jan. 30......	1.3	27	Dec. 16 (17).	2.0	
						Jan. 12 (18)..	1.3	27
Dec. 28 (10).	1.5		Jan. 18 (13)..	1.3				
Jan. 24 (11)..	1.7	27	Feb. 14......	1.6	27	Sept. 19 (18)	1.4	
Feb. 21......	1.8	28	Mch 14.....	1.6	28	Oct. 16......	2.0	27
Mch 20......	1.9	27	*Apr. 9*......	1.9	26	Nov. 12.....	1.7	27
Apr. 16.....	1.7	27	May 5......	1.4	26	Dec. 8......	2.0	26
			June 1......	1.4	27			
July 28 (11)..	1.6							
Aug. 23.....	1.8	26	Aug. 26 (15).	1.6				
Sept. 20.....	1.7	28	*Sept. 23*.....	1.8	28			
Oct. 18......	1.4	28	Oct. 19......	1.6	26			
Nov. 13.....	1.7	26	Nov. 16.....	1.7	28			
Dec. 11......	1.9	28						

EARTHQUAKE RECORDS, WATHEROO MAGNETOGRAMS, OCTOBER 1921-JUNE 1922

The particulars of these records of earthquakes noted on the magnetograms of the Watheroo Magnetic Observatory, Western Australia, are given in the following tables. Table 1 shows also the times of the phases obtained on the seismograph at Perth according to the data supplied by Government Astronomer Curlewis.

TABLE 1.—*Earthquake records for October 10 and November 11, 1921.*

Date 1921	Magnetic record: Element	Greenw. mean time: Beginning	Greenw. mean time: Ending	Remarks	Seismograph record: Phase	Greenwich mean time
		h m	h m			h m s
Oct. 10	Declination.	2 13	2 34	Slight broadening of the traces for all.	P(?)	2 13 06.9
	Hor. Int. . . .	2 13	2 39		L(?)	2 19 12.9
	Vertical Int.	2 19	2 36		. . . .	. . . .
Nov. 11	Declination.	18 45	19 01	Slight broadening.	P	18 43 56.6
	Hor. Int. . . .	18 44	18 56		(?)	18 46 00.5
	Vertical Int.	18 52	18 59(?)	Slight blurring. .	L	18 50 10.4

TABLE 2.—*Earthquake records, January-May 1922.*

Date 1922	Phase	Greenwich mean time: Hor. Int.	Decl'n	Vert'l Int.	Apparent maximum amplitude in hor. int.
		h m	h m	h m	mm
Jan. 1	Begin	12 34	. . . .	. . . .	Small
	End	12 30	. . . .	. . . .	
12	Begin	14 33	14 33	14 34	1.8
	End	14 38	14 38	14 39	
19	Begin	22 12	22 12	22 15	3.5
	End	22 33	22 25	22 27	
20	Begin	7 09	7 08		1.1
	End	7 18	7 15	Indistinct	
Feb. 5	Begin	3 47	3 48	. . . .	. . . .
	End	3 51	3 54	. . . .	
Feb. 5	Begin	18 06	. . . .	. . . .	. . . . (Doubtful as an earthquake record)
	End	Uncertain	. . . .	. . . .	
Feb. 9	Begin	16 55	Indistinct	Indistinct	. . . .
	End	17 03	Indistinct	Indistinct	. . . .
May 9	Begin	13 56	13 56	Indistinct	0.9
	End	14 09	14 09		
23	Begin	4 54	. . . .	. . . .	1.4
	End	5 01			

Mr. H. B. Curlewis, government astronomer of Western Australia, states that there was no apparent earthquake record on the

seismograph at Perth on May 23. He reports earthquake records on May 9, 11, and 12, the last being a very fine one; there are no evidences of earthquake records for May 11 and 12 on the magnetograms obtained at Watheroo.

June 8 and 29, 1922.—There were two possible earthquake records on the magnetograms centering at approximately June 8, $7^h\ 48^m$ Greenwich mean time, and June 29, $20^h\ 21^m$ Greenwich mean time. The government astronomer of Western Australia writes that, because of light trouble, no records were obtained from the seismograph at Perth on either of these dates.

G. R. WAIT, *observer-in-charge.*

AURORAL OBSERVATIONS AT HIGH RIVER, ALBERTA, CANADA, DECEMBER 28, 1921.

1^h A. M.—Two curtains observed; largest runs from N. W. to E., another below it extends from nearly North to N. E., latter is very bright at the W. end *i. e.* N., which appears to be bright because the curtain is running nearly away from the observer and hence more light is observed looking along the curtain than in looking through it. I have observed the same effect before, but I think it was the E. end that seemed to be in line with the eye. It was narrower on the E. end.

7^h45^m P. M.—Faint curtain observed, center nearly N.

9^h00^m P. M.—Faint arch low down, center N. E.

OWEN BRYANT.

9. *Principal Magnetic Storms at Cheltenham Magnetic Observatory, January to June 1922.*[1]

Greenwich Mean Time		Range		
Beginning	Ending	Decl'n	Hor'l Int.	Vert'l Int.
h m	h m	′	γ	γ
Apr. 21, 22 ..	Apr. 22, 12 ..	27.5	186	201

10. *Secular Magnetic Changes in the United States and Local Magnetic Disturbances.*—In the United States Coast and Geodetic Survey Bulletin No. 86, July 31, 1922, it is stated that acccrding to recent repeat observations "the rate of secular change has varied so much recently that values (of the magnetic declination) carried from 1915 are in some cases not dependable." A publication entitled "The Declination in the United States for 1920," by D. L. Hazard, will soon be issued.

According to the same bulletin: 1. W. W. Merrymon, after standardizing his instruments at the Cheltenham observatory, proceeded to Birmingham, Alabama, and took up the investigation of locating iron ore by magnetic methods in co-operation with the Bureau of Mines. 2. The Commanding Officer of the steamer *Explorer* has made an investigation of a considerable area of local disturbance in Chilkoot Inlet, near Skagway, Alaska; the existence of this local disturbance has long been known, as it is in the main channel which is followed by vessels going to Skagway, but no accurate survey has heretofore been made.

11. *Magnetic Resurvey of Japan.*—Under date of July 16, 1922, Professor Tanakadate writes as follows: "We are now repeating the magnetic survey with the new electromagnetic instruments designed by Dr. Watanabe and communicated to the Rome meeting. Three parties have been sent out, one is now in Korea, another in Bonin Islands, and another in Sakhalin. They each carry the Kew magnetometer in addition to the electromagnetic one in order to compare the two methods at several stations. The stations will not be so numerous as in the previous surveys, but we hope to conclude the work in as short a time as possible in order to eliminate the effect of secular variation."

12. *Local Magnetic Disturbances and Secular Changes in the Bermudas.*—Messrs. H. W. Fisk and J. T. Howard, of the Department of Terrestrial Magnetism, returned from the Bermudas to Washington, September 26, after several months' successful investigation of local magnetic disturbances and secular changes. A number of the Department's stations, where magnetic observations had been made by Mr. Fisk in 1907 and by the *Carnegie* staff in 1910, were reoccupied.

[1] Communicated by E. Lester Jones, Director, U. S. Coast and Geodetic Survey; Geo. Hartnell, observer-in-charge. Lat. 30° 44′.0 N; Long. 76° 50.′5 or $5^h\ 07^m.4$ West of Greenwich.

13. *Magnetic observations, Amundsen Arctic Expedition, 1922.*—Dr. H. U. Sverdrup, in charge of the scientific work of the Expedition, mailed magnetic records to the Department of Terrestrial Magnetism, when the *Maud* on July 20, 1922 was at Deering, Kotzebue Sound, Alaska, in order to land Captain Amundsen for his proposed airplane flight from Alaska across the polar area, Kain-ge-skon, Siberia, the magnetic station of 1920 and 1921, was re-occupied on June 30, 1922. After landing Captain Amundsen, the *Maud* was to try to get as far north as the ice-conditions permitted. During the drift of the *Maud* there will be 8 men in all: Wisting, captain; Dr. Sverdrup and his Swede assistant in the scientific work, Neslingren; 2 engineers; one aviator; one sailor and all-round man; and one native cabin-boy.

14. *Return of MacMillan Baffin Land Expedition.*—The Expedition, under the leadership of Dr. Donald MacMillan, with whom the Department of Terrestrial Magnetism had cooperated, returned on September 12 to Wiscasset, Maine, the home port of the Expedition's vessel, the *Bowdoin*. Besides making important contributions to biology, ethnology, geology, meteorology, and tides, the Expedition succeeded in establishing a completely-equipped magnetic observatory at the winter-quarters, on the southwest coast of Baffin Land; this observatory was kept in successful operation from the end of October, 1921, until June 15, 1922, when it was necessary to dismount the instruments for the homeward voyage. During the greater part of this period continuous records of atmospheric-electric variations (potential gradient) were also obtained. The observatory was in charge of R. H. Goddard, an observer of the Department of Terrestrial Magnetism. Mr. G. Dawson Howell, a member of the Expedition, also made magnetic observations on various sledge trips in Baffin Land. Instead of returning aboard the *Bowdoin* he took advantage of the opportunity to travel from Lake Harbor, Baffin Land, on board the Hudson's Bay steamer and thus made magnetic observations at the various Hudson's Bay posts along Hudson Bay and along the Labrador coast.

15. *Watheroo Magnetic Observatory, Samoa Observatory, and Eclipse Magnetic Observations, September 1922.*—After the conclusion of the meetings of the International Geodetic and Geophysical Union and of the International Astronomical Union at Rome, Dr. Louis A. Bauer sailed from Marseilles on May 19 for Western Australia and New Zealand. Arriving at Perth on June 15, an inspection trip was made to the Magnetic Observatory at Watheroo, Western Australia, about 120 miles north of Perth. This observatory, operated by the Department of Terrestrial Magnetism, is almost antipodal to the magnetic observatory of the United States Coast and Geodetic Survey at Cheltenham, Maryland. Arrangements were completed for continuous observations of earth currents at the Watheroo Observatory. This year, also, the instruments are being installed for recording continuously the variations in the electric condition of the atmosphere. Thus, by the end of the present year, the Watheroo Magnetic Observatory will be the most completely equipped of its kind in the Southern Hemisphere.

While in Australia, the arrangements were completed by Dr. Bauer for the special magnetic and electric observations during the solar eclipse of September 21, 1922. Within the belt of totality, besides the astronomical observations, there will be made magnetic observations in accordance with the plan proposed by Bauer and Fleming (*Terr. Mag.*, vol. 27, pp. 83-85) at five well-distributed sta-

tions by the various expeditions. (On September 23 a cablegram was received from Mr. Coleman regarding successful eclipse magnetic observations made at Coongoola, Queensland, a station inside the belt of totality; see also Note 21.)

On July 4-5, Dr. Bauer attended at Wellington a specially-called meeting of the Samoa Observatory Honorary Board of Advice regarding matters pertaining to the continued operation of the Samoa Observatory at Apia, under the joint auspices of New Zealand, the British Admiralty and the Carnegie Institution of Washington.

En route to San Francisco, Dr. Bauer met at Rarotonga D. G. Coleman, observer of the Department of Terrestrial Magnetism, who has been re-occupying a number of the stations on the islands of the Pacific Ocean, and in New Zealand and Australia, where magnetic observations have been made by the Department in previous years. Mr. Coleman was then to proceed, via New Zealand, to the selected eclipse station at Coongoola, Queensland.

16. *"Erda" Aktiengesellschaft für wissenschaftliche Erderforschung, Göttingen, Germany.*—According to several pamphlets received, this appears to be a joint stock company, which in view of its purpose, is called "an institute for practical or applied geophysics." Its prime purpose is to place at the disposal of industry both theoretical knowledge and instrumental equipment for operations of a geophysical nature. Among the operations which, upon application, will be undertaken by the institute, are the following: Magnetic observations to determine the distribution of the magnetic elements and their local anomalies; electric measurements of natural and industrial earth currents; determination of the propagation of electric currents and electric (Hertzian) waves in the interior of the Earth; atmospheric-electric observations, etc.

17. *Journal for applied geophysics.*—Announcement has been received from the editor, Dr. Richard Ambronn, of the publication by the firm Gebrüder Bornträger, Berlin, of a new journal, to be called "Zeitschrift für angewandte Geophysik." The first issue has come to hand.

18. *International Meteorological Committee.*—The English report of the meeting at London in September, 1921 has been published as M. O. 248, Air Ministry, Meteorological Office. The following officers constitute the Bureau of the Committee, which consists at present of 16 directors of national meteorological institutes: Sir Napier Shaw, *president;* Professor E. van Everdingen, *vice-president*, and Director Th. Hesselberg, *secretary*. The members of the *Commission for Terrestrial Magnetism and Atmospheric Electricity* are: A. Angot, *president;* E. van Everdingen, *secretary;* T. Banachiewicz, L. A. Bauer, V. Carlheim-Gyllensköld, A. Ferraz de Carvalho, S. Chapman, C. Chree, J. Jaumotte, O. Krogness, A. Crichton Mitchell, G. Melander, L. Palazzo, C. Ryder, Napier Shaw, G. C. Simpson, Frederic Stupart, A. Wolfer.

19. *Personalia.—Prince Albert of Monaco*, distinguished for his oceanographical studies, died at Paris on June 27, at the age of seventy-five years. Dr. *G. Angenheister* has accepted a position on the staff of the Geodetic Institute at Potsdam, Germany. Rev. *A. L. Cortie*, director of Stonyhurst College Observatory, received an honorary doctorate at the recent celebrations of the seven-hundredth anniversary of the University of Padua. Colonel *E. Delcambre* has been appointed director of the French Meteorological Office. Dr. *B. Meyermann*, formerly director of the Observatory of Tsingtau, has been appointed to succeed

Prof. *Ambronn*, who has retired from the directorship of the Göttingen Observatory. Prof. *R. Spitaler* is giving a course in atmospheric electricity at the University of Prag, during the summer semester 1922. Dr. *W. F. G. Swann* has resigned his professorship of physics at the University of Minnesota and has accepted a similar post at the University of Chicago. Dr. *Louis A. Bauer* has been made a "corresponding member" of the Société de Géographie de Lisbon, Portugal. Prof. *J. A. Pollock*, well known for his investigation of the ions of the atmosphere, died on May 24, after a short illness, at the age of fifty-seven years. Dr. *S. K. Banerji* was appointed in April director of the Bombay and Alibag observatories.

20. *Chauveau's Atmospheric Electricity.*[1]—Workers in atmospheric electricity will welcome an extended treatise on atmospheric electricity by M. Chauveau. From the preface we learn that the completed work will consist of three principal subdivisions devoted, respectively, to (a) historical introduction, (b) the electric field of the atmosphere, and (c) the ionization of the atmosphere. Only the first fascicle, about 100 pages, has thus far appeared. It is devoted entirely to the historical introduction, which, in three chapters, traces the development of ideas and methods during three well-defined periods: the first (1750 to about 1860), from Franklin to Peltier; the second (1860 to 1899), from William Thomson to Exner and his pupils; and the third or modern period, in which the names of Elster and Geitel and of Ebert are predominant. That the author's treatment of the subject is unusually detailed is obvious from the above outline. Accordingly one finds here many matters of historical interest that are not included in other general works on atmospheric electricity, together with numerous references to original sources.

21. *Magnetic Character of day of solar eclipse, September 21, 1922.*—According to information received from the Director of the United States Coast and Geodetic Survey, the magnetic character of the days at the time of the eclipse, as judged by the magnetograms of the Cheltenham Magnetic Observatory, Maryland, the times given being Greenwich civil mean time, was as follows: September 20 was quiet until 18^h (6 P. M.), when H (horizontal intensity) and Z (vertical intensity) were slightly disturbed, values averaging about normal, this disturbed condition lasting until September 21, 7^h. Between September 21, 0^h and 1^h, there was a downward bend in D (declination) of some 13 minutes. After September 21, 7^h, the magnetic elements were quiet and normal. (Since the solar eclipse began on September 21, $2^h\,04^m$, G. M. T., and ended at $7^h\,16^m$, there was a slight magnetic disturbance, which began 8 hours before the eclipse and continued throughout the eclipse period. This cosmic disturbance may possibly complicate the detection of the small effect to be ascribed to the eclipse; however, before reaching a definite conclusion, it will be best to await the reports from the eclipse expeditions and from observatories in other regions of the Earth.)

[1] B. Chauveau, *Électricité Atmosphérique*, premier fascicule, introduction historique. Paris, Gaston Doin, Éditeur, 1922.

LIST OF RECENT PUBLICATIONS

A. Terrestrial and Cosmical Magnetism.

ANTIPOLO OBSERVATORY. Hourly results of the observations made at the Magnetic Observatory of Antipolo, near Manila P. I., during the calendar year 1918. (Part IV of the annual report of the Weather Bureau for the year 1918.) Manila, Bureau of Printing, 1921, 47 pp. 29 cm.

AZORES. Résumé d'observations. Service Météorologique des Açôres. Années 1913 à 1920. Lisbonne, Imprimerie Nationale, 1914-1921, 17x32 cm. ca. 20 pp. [Each résumé contains the values of the three magnetic elements at the S. Miguel Magnetic Observatory during the year to which the résumé applies. These values are the means of observations made at different times in the course of the year.]

BANGKOK. Report on the operations of the Royal Survey Department of the Army for the year 1919-1920. Bangkok, Bangkok Daily Mail, 1921 (88 with 3 maps). 34 cm. (On pages 8-10 are given the results of magnetic observations 1905-1920).

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Terrestrial Magnetism *and* *Atmospheric Electricity*

VOLUME XXVII DECEMBER, 1922 No. 4

ON THE METHODOLOGY OF FINDING AND REPRESENTING THE DISTRIBUTION OF A NATURAL ELEMENT OVER A CERTAIN REGION OF THE EARTH'S SURFACE, WITH SPECIAL REFERENCE TO TERRESTRIAL MAGNETISM.*

BY BORIS WEINBERG.

1. *The problem.* Let E denote the value of a natural element at a given point and a given time, *e. g.*, the temperature, humidity or pressure of the air, the magnetic force, the geological formation, etc. We shall restrict ourselves here to dealing with elements which can be measured quantitatively and the variations of which are continuous both in space and with time. Furthermore, if we consider only the values of the natural element at the surface of the globe, we may write

$$E = \Phi\ (\phi, \lambda, t) \tag{1}$$

where ϕ and λ are the latitude and longitude of a point at the surface of the globe and t is the time. Our problem is then to find and represent this function for the whole globe or a part of it by means of observations of E, taken at different points and at different times.

The ideal solution would be to express E as an analytical function of ϕ, λ, and t, thus making it possible to calculate the value of E for any point on the globe at any time. However, this ideal is not attainable owing to the great variability of all the natural elements. Therefore, the problem is regarded as solved for a given region and interval of time, if with the aid of tables or graphical representations we can predict the approximate values of E at different points within this region for any moment of this interval. As an example of a satisfactory solution, we may mention charts of the distribution of the magnetic elements accompanied by indications or charts of the annual changes.

* Based on two long manuscript articles, dealing with the general method of representing the distribution of some geophysical element and accompanied by 13 figures. The abstract was kindly prepared for the Journal by Dr. H. U. Sverdrup, and revised by the author.—*Ed.*

2. *The real variation of a natural element with time.* Let us first discuss only the question of the changes of E at a given point with the time. If the element can be registered, then the registrations will give us the *real* values of E for each moment t, only smoothed by the inertia of the registering instrument. The real changes of E, thus obtained, can be regarded as composed of:

I. Secular changes;
II. Cyclic changes of definite periods (or "regular periodic");
III. Cyclic changes of variable periods (or "irregular periodic");
IV. Rapidly varying non-cyclic changes (or "accidental aperiodic");
V. Slowly varying non-cyclic changes (or "systematic aperiodic"),

or in analytical form:

$$\begin{aligned} E_{\phi_1\lambda_1} = {} & \mathrm{F}_T(t) + \mathrm{f}_{T_1}(t) + \mathrm{f}_{T_2}(t) + \ldots\ldots\ldots \mathrm{f}_{T_n}(t) + \\ & \phi_{\tau_1}(t) + \phi_{\tau_2}(t) + \ldots\ldots\ldots\ldots + \phi_{\tau_n}(t) + \\ & \alpha_1(t) + \alpha_2(t) + \ldots\ldots\ldots\ldots + \alpha_n(t) + \\ & \beta_1(t) + \beta_2(t) + \ldots\ldots\ldots\ldots + \beta_n(t) \end{aligned} \qquad (2)$$

Such a decomposition is more or less arbitrary: the only group which without any doubt can be differentiated from the others is the second which contains the regular periodic changes.

If continuous registrations of E are not at hand, but only values of E at different moments, then the question may arise as to how to find the *real* value of E for any moment between two observations. Theoretically, this problem cannot be solved, but the practical solution is to interpolate in some way or other between the observed values. This implies, however, certain mathematical assumptions which are enumerated and treated in detail in the article and of which the most common are that the element is changing uniformly between two successive observations, or that the irregular aperiodic changes are small. To be sure that such is the case, the author recommends making, instead of a single reading, several readings during an interval of time which is small if compared with the intervals between such separate groups of readings. If such is not the case, then any attempt to find the real value of E between two observations must fail. The interpolation may be made graphically by taking the values sought, from a curve drawn through the points determined by observations, or arithmetically by means of some formula for interpolation. Both methods are, however, deficient as they introduce discontinuities in the change of the

element: the graphical, because it is not possible to draw a curve which, when magnified, will not show numerous breaks; the arithmetical, because no interpolation formula can take full account of the curvature of the curve, representing the real change of the element. Usually an interpolation-formula, which takes account of the second differences, will be sufficient. Let us introduce the following notation:

E_i, the value of E at the time $t = t_i$;
T, the constant time difference between two observations;
$E(t)$, the value of E at the time t where $t_{i+1} > t > t_i$;
$\Delta E_i = E_{i+1} - E_i$;
$\Delta^2 E_i = \Delta E_{i+1} - \Delta E_i = E_{i+2} - 2E_{i+1} + E_i$.

After an analysis of the correspondence between the mathematical assumptions mentioned above and the different formulas for interpolation, the author reaches the conclusion that the most satisfactory formula is:

$$E(t) = E_i + \frac{t-t_i}{T} \Delta E_i + \frac{(t-t_i)(t-t_i-T)}{2T^2} \; \frac{\Delta^2 E_i + \Delta^2 E_{i-1}}{2} \qquad (3)$$

3–5. *The normal change of an element with the time.* The real change of an element being either unobtainable or too complicated for practical or theoretical purposes, the problem of finding the real change is often replaced by the problem of finding the *normal* change of the element. Since there is no general agreement on the conception of normal change, we shall have to define it in such a way that our definition will agree with the most usual interpretations. By normal change we will understand the change in E free from all irregular periodic or aperiodic accidental or systematic changes. Of the components of E, we keep only the first two, the secular and the regular periodic, thus writing:

$$E_{norm} = \mathrm{F}_T(t) + \mathrm{f}_{T_1}(t) + \mathrm{f}_{T_2}(t) + \ldots\ldots \mathrm{f}_{T_n}(t) \qquad (4)$$

Each separate term on the right side of this equation may also be called a normal change, for instance, "normal secular change," "normal diurnal change," and so on.

If E has been registered continuously, the process of finding the normal change usually consists in taking the values of E for equidistant intervals of t from the graphs and from these values to compute the separate periodic functions $f_1, f_2, \ldots f_n$, starting with the one which has the shortest period. If the registrations show great aperiodic changes, it is advantageous to obtain the mean

values of E for the time-intervals either by summation, or graphical integration, and to coordinate these values with the mean time of the interval.

If only separate values of the element are known, the computation of the normal change will be much more uncertain, chiefly on account of the presence of values which represent abnormal conditions. These may sometimes be rejected, but there is no safe criterion for the rejection of "discordant" observations, although many have been proposed. Accordingly, the determination of the normal change is often arbitrary because the result, to a great extent, depends upon where the limit for rejection has been drawn.

6. *The smoothed change of an element with the time.* In order to weaken, in the first place, the influence of systematic aperiodic changes of not very long duration, the method of smoothing the results of observation is used. We can define what we mean by the smoothed value of E by the equation:

$$E_{smooth} = \mathrm{F}(t) + \mathrm{f}_1(t) + \mathrm{f}_2(t) + \ldots\ldots + \mathrm{f}_n(t) + r\,[\phi(t) + \alpha(t) + \beta(t)] \qquad (5)$$

where $$0 < r < 1$$

The process of smoothing consists in substituting for each observed value E_p, a smoothed value E'_p derived from the value E_p and the preceding and following values:

$$E'_p = l_0 E_p + l_1 (E_{p-1} + E_{p+1}) + l_2 (E_{p-2} + E_{p+2}) + \ldots + l_k (E_{p-k} + E_{p+k}) \qquad (6)$$

where $l_0, l_1 \ldots\ldots l_k$ are numerical constants, which are subject to the condition

$$l_0 + 2\,(l_1 + l_2 + \ldots\ldots + l_k) = 1 \qquad (7)$$

In order that the values E'_p may actually deserve the name of smoothed values, the following requirement must be fulfilled: It must be possible to find a function

$$E(t) = E(t, E_{p-k} \ldots E_p \ldots E_{p+k}) \qquad (8)$$

which is continuous, preserves its form for each of the intervals between the moments

$$t_{p-k} \ldots\ldots t_p \ldots\ldots t_{p+k},$$

gives identical values for these transitory moments, and the mean value of which shall be equal to the corresponding smoothed value, that is:

$$\int_{t_p - \frac{1}{2}T}^{t_p + \frac{1}{2}T} E\,(t)\,dt = E'_p\,T \tag{9}$$

The smoothing can be made graphically or arithmetically. The graphical smoothing, which is of a rather arbitrary character, consists in drawing a smooth curve, not through the points E_p, t_p in the (E, t) diagram, but near them and taking for the values of E'_p, the values of the ordinates of the curve.

The arithmetical smoothing consists in computing the values E'_p by means of fixed values $l_0, l_1 \ldots . l_k$. The same process may be repeated and a second set of smoothed values E''_p computed, and so on. The usual formula for smoothing is the one in which all l's have the same value and k is usually taken equal to 1 or 2, as, for example, $k=1$:

$$E' = \frac{1}{3}\,(E_{p-1} + E_p + E_{p+1}) \tag{10}$$

But these formulas do not seem to satisfy the idea of smoothing as expressed in equations (8) and (9); they do not produce any function $E(t)$, which gives a smooth change of E.

The following method of smoothing may be preferable. Let us regard one observation made at the time t_p as represented by the rectangle $ABCD$, having for altitude an ordinate $OP = E_p$ and for base, a time interval $AD = T$ (see Fig. 1). The use of formula (10) for smoothing implies that we replace this rectangle by the rectangle $abcd$, the base of which is equal to $3T$ and the height equal to $\frac{1}{3}\,E_p$. The adjacent rectangles, which are not indicated in the figure, are treated in the same way and the smoothed value E'_p is the sum of the three rectangle parts over the base $AD = T$. Now, instead of flattening the rectangle $ABCD$ into another rectangle, we will transform it into an area limited by the curve

$$E = \frac{hE_p}{\sqrt{\pi}\,T}\,e^{-\frac{h^2\,(t-t_p)^2}{T^2}} \tag{11}$$

and determine the coefficient h so that the area, bounded by the curve and the ordinates AB and CD will be one-half of the area $ABCD$, which gives us

$$h = 0.8538\ldots \tag{12}$$

The method here suggested can also be described in other words. The curve defined by (11) gives the probability according to Gauss's law for E, assuming the value E_p within the different time intervals

$T_{p-k} \ldots T_{p+k}$, and by means of (12), we arbitrarily fix this probability within the interval $T_p = AD$ at 0.5. The probabilities for E, assuming the value E_p within the time intervals T_{p-1} etc., can easily be found by evaluation of the integral $\int e^{-x^2}\,dx$. We denote the probabilities by W_1, W_2 .... and find

$$W_1 = 0.2286\ldots;\quad W_2 = 0.0210\ldots;\quad W_3 = 0.004\ldots \tag{13}$$

These values multiplied by E_p evidently represent the areas limited by the curve (11) and the ordinates DC, dc, etc. The smoothed value E'_p corresponding to the time t_p can be regarded as the sum of the areas over the base AD, limited by the curve (11) and the corresponding curves for E_{p-2}, E_{p-1}, etc.

$$E'_p = 0.02\,E_{p-2} + 0.23\,E_{p-1} + 0.5\,E_p + 0.23\,E_{p+1} + 0.02\,E_{p+2} \tag{14}$$

Equation (14) gives us separated smoothed values. However, it is evident that we can easily determine a function $E(t)$ which gives us continuous smoothed values, thus fulfilling the condition (9). The function $E(t)$ is simply the sum of the ordinates of the curves E corresponding to any value of t

$$E(t) = \sum_{i=p-k}^{i=p+k} \frac{h\,E_i}{\sqrt{\pi}\,T}\, e^{-\frac{h^2(t-t_i)^2}{T^2}} \tag{15}$$

where it is usually sufficient to take $k=2$; see (13). The formulas here developed have given very satisfactory results in practice.

The final result of the computations made to determine the real, normal or smoothed change of an element with time may be represented by a graph, a table, or an empiric formula. These different representations have both advantages and disadvantages, treated in detail in the article.

7. *The interval of time between separate observations and the limit of precision necessary for finding the change of an element with time.* The author gives here certain suggestions concerning these questions.

8. *The representation of the change of an element with time.*

9. *The representation of the distribution of an element over a certain region.* Let us suppose that we know the values of an element E for a number of points $(\phi.\ \lambda)$ of a certain region for a given moment $t=t_0$, either from simultaneous observations or from observations reduced to the same epoch, the observation of an element at *all* the points over a certain area being physically impossible.

The distribution of the element is generally so complicated that its analytical representation is impossible. The tabular representation usually has the form of a table with two entrances, or a set of tables for each of which, one of the independent variables, ϕ or λ, has a constant value. Three different graphical representations may be mentioned:

a. A series of curves showing, for instance, the variation of the element with longitude for different values of latitude;
b. Maps with shaded regions, in which the value of the élement lies within certain limits;
c. Maps with isolines, i. e., lines along which the element has a constant value.

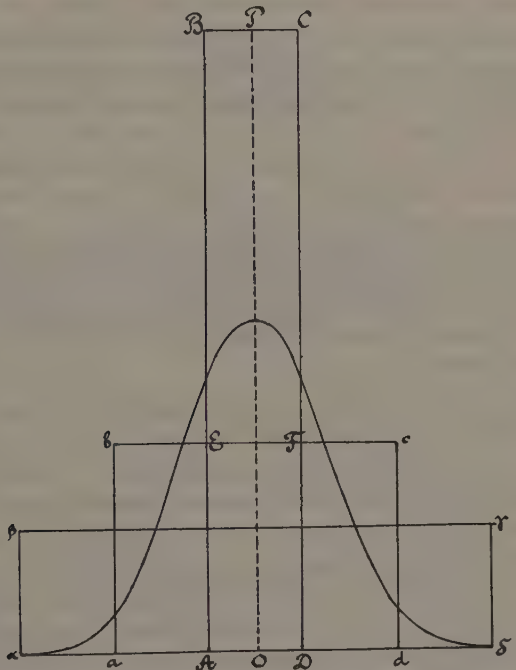

FIG. 1.

The last method is the most familiar, but the defects of this representation become obvious, when we discuss how to find the value of the element represented by the isolines at any point not on the isolines. If the isolines are running smoothly and their distances for equidistant values of the element are varying slowly, then we may find the value at the point by linear interpolation. However,

if the shape of the isolines and their mutual distances are irregular, the graphical interpolation will depend on the direction of the straight line along which we shall interpolate and the differences between the estimated value at the point may reach 20 or 30 per cent of the difference between the values of the element at two consecutive lines.

The same difficulties arise when we try to interpolate from a table with double entrance (ϕ and λ). The usual formulas for interpolation do not take account of second differences or, in other words, the formulas for determining the value E at a point ϕ, λ for which

$$\phi_0 < \phi < \phi_1; \quad \lambda_0 < \lambda < \lambda_1$$

contain only the values E_{00}, E_{01}, E_{10} and E_{11} corresponding to the four adjacent points, ϕ_0 λ_0, etc.; but even in this case there can be four different formulas according to the values: $\dfrac{E_{10} - E_{00}}{\Delta \phi}$ or $\dfrac{E_{11} - E_{01}}{\Delta\phi}$ and $\dfrac{E_{01} - E_{00}}{\Delta\lambda}$ or $\dfrac{E_{11} - E_{10}}{\Delta\lambda}$, which are attributed to the gradient of the element along the meridians and the parallels.

The author points out the incompatibility of the assumption of the linear change of these gradients and of the element itself, and gives the following formula for interpolation which contains some of the second differences:

$$\begin{aligned} E = E_{00} &+ \frac{E_{10} - E_{00}}{\Delta \phi} (\phi - \phi_0) + \frac{E_{01} - E_{00}}{\Delta \lambda} (\lambda - \lambda_0) + \\ &\frac{E_{11} - E_{10} - E_{01} + F_{00}}{\Delta \phi \, \Delta \lambda} (\phi - \phi_0)\ (\lambda - \lambda_0) + \\ &\frac{E_{20} - 2\,E_{10} + E_{00}}{2\,\Delta\,\phi^2} (\phi - \phi_0)\ (\phi - \phi_1) + \\ &\frac{E_{02} - 2E_{01} + E_{00}}{2\,\Delta\,\lambda^2} (\lambda - \lambda_0)\ (\lambda - \lambda_1) \end{aligned} \qquad (16)$$

It should be noted that the graphical, as well as the arithmetical, interpolation leads to a break in the continuity of the values of the gradient of the element; the graphical in crossing an isoline, the arithmetical in crossing a meridian or a parallel.

10. *The real distribution of an element over a certain region.*

11. *How to find the points of equal values of an element over a certain region.*

12. *The desirability of perfecting the method of finding the position of the points of equal value.*

13. *The most approximate distribution of stations in the survey of a certain region.*

14. *The problem of drawing the lines of equal value.* Having shown in paragraph 9 that the representation of an element over a certain region, neither by means of lines of equal values nor by a table, permits us to determine the value of the element at any point with a high degree of accuracy, the author shows the impossibility of solving even approximately the inverse problem, namely, that of finding the distribution of an element by means of observations made at isolated points. The first step in solving this problem is to find the position of the points of equal values, i. e., the points where the element has the selected equidistant values. The second step is to draw the lines of equal value. For the determination of the points there are—usually silently made—several assumptions, the most important of which is, that the element in the vicinity of a station varies proportionally with the distance from the station. However, a simple geometrical consideration shows that this assumption is generaly incorrect. The relation between the element E and the geographical coordinates ϕ and λ can be represented as a surface

$$z = f(x, y) \tag{17}$$

The above-mentioned assumption implies that this surface has a so-called conical point over the station, x_0 y_0, or that the surface itself is a plane. Another assumption, which is often made although also not expressed, and which is really a consequence of the first, is that if the element has the same value at two adjacent stations, then it has the same value on the straight line connecting these stations. A geometrical consideration shows that this assumption implies that the surface (17) is not only a linear surface but a cylinder. Therefore, the only case when both assumptions are fulfilled is the one when surface (17) is a plane.

To illustrate the methods by which these assumptions are used for finding the "isopoints," or points of equal values, we may take as an example the discussions of the results of the magnetic survey of a part of the Government of Petrograd, which have been made independently by M. A. Rykačev[1] and E. A. Kučinskij.[2] Rykačev simply determines the "isopoints" by interpolating between two adjacent stations, supposing that the element changes linearly

along the line connecting the two stations. Kučinskij uses another method. He combines not only adjacent stations but stations, the distance between which is less than three times the average distance between all stations, and determines much more numerous points of equal values by linear interpolation between such pairs of the stations. The different ways in which Rykačev and Kučinskij draw the "isolines" will be discussed later.

The author, in his investigations of the distribution of the elements of terrestrial magnetism in Siberia,[3] has used another method. The magnetic observations were usually made along certain routes which were divided into rectilinear parts. If the deflections from the straight line were noticeable, the observed values at the points nearest to the straight line were reduced to the line by means of an approximate value of the gradient of the element, obtained from a preliminary isolinic map. For the varation of the element along such a straight line, one of the following formulas was adopted:

$$E = E_0 + \alpha\,(\phi - \phi_0) \tag{18}$$

or

$$E = E_0 + \beta\,(\lambda - \lambda_0) \tag{19}$$

where E_0, α and β were computed by means of the method of least squares. The position of the "isopoints" on these straight lines could then be computed. If the stations were scattered irregularly, or over a limited part of the region, the linear expression

$$E = E_0 + \alpha\,(\phi - \phi_0) + \beta\,(\lambda - \lambda_0) \tag{20}$$

was adopted, and the constants in this equation were determined by means of the method of least squares.

A comparison between the three methods for finding the "isopoints" carried out in the case of the above-mentioned observations in the Government of Petrograd, show that, if the stations are 20 or 30 km. apart, the position of the real values of the declination (accurate to 1′) cannot be found with any higher degree of accuracy than 2 km. in a quiet region, and this limit amounts easily to 6 km. in a region where the "anomalies" of declination are of the order of 15′ to 20′.

Another method of finding the "isopoints" may also be suggested according to which the points derived from different combinations of stations receive different weights according to their distance from the nearest station. The weight may be indicated by representing the "isopoint" as a circle, the area of which is proportional

to the weight. This method is intermediate between those used by Rykačev and the author, and that used by Kučinskij.

The conclusion which may be drawn from these considerations is that the methods of finding the "isopoints" need a fundamental revision and perhaps ought to be made subject to a general agreement between scientists interested in the distribution of natural elements over the surface of the globe, in order to make possible a comparison of the results of different investigations.

In paragraph 13, the author deals with the problem of effecting a distribution of stations such as to make possible the precise computation of the value of an element at an intermediate point and, from considerations based on the theory of surfaces and on the solution of the problem of the number and form of differential parameters of a function of two independent variables, shows that the triangular disposition of the stations, besides other advantages which it has, for example, over the quadratic disposition, permits such a computation.

The "isopoints," the determination of which has been dealt with in paragraph 11, must be regarded as representing the *real* "isopoints." When now in paragraph 14 the author proceeds to the problem of drawing the "isolines," we meet with the question as to what kind of lines we seek. The real distribution of an element may be regarded as a sum of different terms:

$$\begin{aligned} E(\phi, \lambda) = {} & f_1(\phi, \lambda) + f_2(\phi, \lambda) + \ldots\ldots\ldots + f_n(\phi, \lambda) \\ & + \phi_1(\phi, \lambda) + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ & + \alpha_1(\phi, \lambda) + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ & + \beta_1(\phi, \lambda) + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \end{aligned} \tag{21}$$

corresponding to expression (2) for the different changes of an element with time, only that the term representing the secular variation is missing because the surface of the globe is limited. The terms f_1, f_2....... the author calls the *telluric distribution;* the terms ϕ_1, ϕ_2....., the *irregular periodic local disturbances;* the terms α_1, α_2..... and β_1, β_2......., the *aperiodic regional disturbances*, respectively.. The *normal telluric* distribution is defined as the sum of the terms f_1, f_2...., the *normal regional distribution*, as the sum of the terms f_1, f_2... and β_1, β_2..., and the *smoothed distribution*, as:

$$\begin{aligned} E_{smooth} = {} & f_1(\phi, \lambda) + f_2(\phi, \lambda) + \ldots\ldots\ldots f_n(\phi, \lambda) \\ & + r\,[\,\phi(\phi, \lambda) + \alpha(\phi, \lambda) + \beta(\phi, \lambda)\,] \end{aligned} \tag{22}$$

where $0 < r < 1$

Before describing the methods used by the author in his investigations, we will mention the methods used by Rykačev and Kučinskij for tracing the "isolines." Rykačev simply connects the "isopoints" by straight lines and gets thus a broken "isoline." Kučinskij obtains by his method numerous "isopoints" lying in strips. He first draws a smooth line in the middle of this strip and then draws a final wave-like line through the points lying half way between his smooth curve and the "isopoints." No attention is paid to the weight of the "isopoint."

The following method was used by the author in determining the smoothed distribution of the magnetic elements reduced to the epoch 1910.[3] The "isopoints" were determined by means of equations (18) to (20) and their positions were plotted on maps. They were distributed in strips resembling parabolic curves, hence the equations:

$$\left.\begin{aligned} \phi &= \phi_0 + \gamma\,(\lambda - \lambda_0) + \delta\,(\lambda - \lambda_0)^2 \\ \lambda &= \lambda_0 + \gamma'\,(\phi - \phi_0) + \delta'\,(\phi - \phi_0)^2 \end{aligned}\right\} \qquad (23)$$

were introduced to represent the "isolines." The coefficients in these equations were determined by means of the method of least squares. The deviations in longitude and latitude of the "isopoints" from the "isolines" (22) could be regarded as partly due to errors of observation, partly to errors in reduction to 1910, and partly to local disturbances. Hence, it seemed appropriate to apply a method of smoothing to them. After using the method of smoothing described in paragraph 6, a second set of points of intersections of the "isolines" with the meridians and parallels was found. This second set showed regular variations between these points of intersection, so the next step was to express it by means of the following equations, again using the method of least squares:

$$\left.\begin{aligned} \phi &= \phi_0 + \eta\,(E - E_0) + \epsilon\,(E - E_0)^2 \\ \lambda &= \lambda_0 + \eta'(E - E_0) + \epsilon'\,(E - E_0)^2 \end{aligned}\right\} \qquad (24)$$

The last step consisted in smoothing the deviations of the second set from the values computed by (24). The fourth set thus obtained was regarded as the final values for the intersection of the smoothed "isolines" with the meridians and parallels. No attempt was made to express the result in analytical form.

In order to compare the system of lines derived by this method with that drawn by Rykačev and Kučinskij, the method here described was also applied to the observations treated by them, and

the lines were also represented by an analytical expression of the second degree in relation to $\phi - \phi_0$ and $\lambda - \lambda_0$. The result was that the mean deviation of the observed values from the smoothed values computed by the author was slightly less than the mean deviation resulting from the "real" lines of equal values obtained in other ways.

The preference of the author's method was still more evident when he treated—also by different methods—the distribution of the vertical component in a case where the latter could be calculated for every point of the region (a field disturbed by some supposed ellipsoidal and cylindrical masses of given dimensions, orientations, positions and changes).

15-16. *The time interval between consecutive surveys, the density of stations and the accuracy of the observations.* Considering the great differences between the natural elements which are subject to observation, it is impossible to give any rules of general application. The selection of time-interval, density of stations and the limit of accuracy depend not only upon the changes of the element with time and space, but also upon the aim of the observations, e. g., whether the real, the normal, or the smoothed distribution of the element is sought. Some theoretical considerations may give help toward answering the questions here raised (cf. § 12). In most cases, however, the answer can only be found by experience, namely, by making "micro-surveys"—observations at several "points" of a "station."

17. *Finding and representation of the changes of the distribution of an element over a certain region.* We have until now dealt separately with the change with time and the distribution over a certain region, and have, in both cases, discriminated between real, normal and smoothed change or distribution. If we now consider both together we obtain nine different combinations, the real change of the real distribution, and so on. Generally one of these combinations is sought, namely the smoothed change of the smoothed distribution. The problem of finding this does not differ materially from the separate problems treated before, but is more complicated, because it deals with three independent variables. The practical solution of the problem consists in:

a. Organization of stations where the change of the element with time is observed continuously;

b. Surveys of the whole region which have to be repeated at certain intervals.

The observations can be treated according to the methods here described. The results can be represented by sets of tables or sets of maps accompanied by diagrams, giving the change with time at certain selected stations, etc. Charts of the annual change of an element are graphical representations of a peculiar type.

18. *The density of the stations and the precision of the measurement by the magnetic surveys.*

We shall try now to apply these general considerations to the particular case of a magnetic survey, with special reference to Asiatic Russia.

For populated regions with a sufficient number of permanent or temporary magnetic observatories or stations, real values of declination and inclination may be known with an accuracy of $\pm 2'$ and of horizontal intensity within about $\pm 10\gamma$. This limit is set by uncertainty as to reduction to a certain epoch and by errors of observation. However, it is not possible to find the real value of D at a point not coinciding with a point of observation within less than $\pm 5'$ even if the stations are about 20 km. apart (see paragraph 11).

If we consider the field observations made in regions thinly populated, where the means of transportation are very difficult, the maps deficient, and for which data regarding annual variations are few, it is no exaggeration to assume that the real value of D (declination) for a station, after reduction to the epoch, can be considered to be known only within some $\pm 10'$, of I (inclination) within $\pm 5'$ and of H (horizontal intensity) within $\pm 10\gamma$. For a point lying off one of the routes, the error of the interpolated "real" value of D can easy exceed some $20'-30'$, of I some $10'-15'$, and of H some $30-50\gamma$.

In such cases the use of instruments of high precision would be justified if after 20 to 30 years it would be possible to secure along the route of the expedition even a few repeat stations. For many regions—particularly for well-nigh half of the 86 per cent of the area of Siberia which is still entirely unexplored in respect to terrestrial mgnetism[4]—the realization of such fundamental stations is practically impossible. Besides, the determination of the annual change of one of the elements of terrestrial magnetism, deduced from the comparison of determination made now with a smaller precision but at a greater number of points (the author emphasizes again the idea of "micro-surveys") with the determinations which may be made in several points of the same district in 20 to 30 years, will be sufficiently trustworthy.

Therefore it is quite legitimate to ask the question whether it is possible to reduce the requirements usually made as to the instruments and to the methods used in field observations during the surveys in such inaccessible regions as, for instance, the greater part of Asiatic Russia? Is it not preferable to have determinations of a moderate precision than to have none at all? Positive answers to these questions would at once make possible magnetic surveys of many regions which must otherwise wait for several decades.

In this respect special attention deserves to be drawn to the words of L. A. Bauer in his general suggestions[5] to the observers of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington: "Local disturbances frequently exceed the diurnal-variaton correction. Hence, in disturbed regions, and if the time is limited, multiplicity of stations, rather than great accuracy at one station, must be the endeavor." Since only a great number of stations can give information regarding disturbances, and since in Siberia the time for observation is practically limited to the summer, the author forms L. A. Bauer's words thus: "Multiplicity of stations must be the endeavor, even at the expense of a certain lowering of the precision of the measurement."

In favor of such assertion, the author quotes one more consideration: It is practically impossible to find the real distribution, hence, the purpose of a magnetic survey—at least of the first survey of a region not yet visited by magneticians—must be to find the smoothed or even the normal regional distribution of magnetic elements, and for this purpose it is sufficient to have determinations of an inferior precision but, if possible, free from local influences. This consideration can be corroborated by the following table, which gives the values of the mean deviations of the values of *D*, *I* and *H* for the magnetic survey of Japan of 1913 from the "normal" distribution given by T. Nakano[6], computed by the author separately for the "normal" stations and for the "anomalous" stations, as well as for both kinds together.

TABLE 1.

Japan, 1913	ΔD	ΔI	ΔH
	$'$	$'$	γ
Normal stations....	± 6.4	± 6.0	± 71
Anomalous stations.	± 35.5	± 34.6	± 286
All stations........	± 10.3	± 9.8	± 100

It may be noted that, assuming the average amount of the local disturbing force to be of the order of 200γ[7], the formulas which the author has deduced in the quoted paper give for $I = 49°$ and $H = 0.30$ c. g. s.,

$$\triangle D = \pm 12', \ \triangle I = \pm 8', \quad \triangle H = \pm 100\gamma.$$

The reduction of the requirements to the precision of the observations, compared with the precision which can be obtained with a first-class instrument during a stay lasting not less than 8 hours, can be reached in three ways:

a. Abbreviation of the program of the observations at each station;
b. Simplification of the methods of the determinations;
c. Using instruments of another type.

If, as an example of a first-class instrument, we take the C. I. W. (Carnegie Institution of Washington) magnetometer-inductor, a full set of observations comprises:

a. Observations of the Sun;
b. Determination of the inclination;
c. Determination of the declination with a preliminary detorsion of the ribbon and with the inversion of the magnet;
d. Oscillations and torsion;
e. Deflections;
f. $=e$; $g=d$; $h=c$ (without detorsion); $i=d$; $j=a$.

If the interval of observation includes noon, the circummeridian observations of the Sun are added. If the time is limited, some points of this program have to be canceled.[8] Personally, the author recommends, as far as the items c to h and j of the program above are concerned, to sacrifice those in the following order: (1) detorsion, (2) determination of the torsion, (3) repeating of the inversion of the magnet by declination observations, (4) repeating of the deflections, (5) repeating of the oscillations, (6) deflections entirely, (7) inversion of the magnet entirely, (8) number of pointings on the Sun (4 and even 2 instead of 8), (9) pointings on the Sun and determinaton of the declination entirely, or oscillations entirely.

A considerable economy of time is attained when two observers are working simultaneously, and there is a separate astronomical theodolite and also a special stand with a horizontal circle for the magnetic house. Then it is possible to mount at once the earth-inductor, the galvanometer, the magnetometer, and the astronomical theodolite, the two latter being placed on one straight line with the chosen mark. The presence of a separate theodolite, be-

sides increasing the precision of the readings (from 1′ of the C. I. W. magnetometer to 10″ and 20″ of the Hildebrand's theodolite—small model—which the author usually takes with him on his trips), has a calming effect, in the case of a cloudy sky, on the observer, who is now sure that if the Sun appears even for a short time the station will not remain without determination of D. But even if the theodolite of the magnetometer has to be used for the observations of the Sun, a separate circle for the magnetometer is very useful. As an illustration, the author quotes the observations at Sunijarskoje in 1914, where, owing to the fact that on the steamboat his assistant, the late A. A. Belov, and himself had previously mounted the earth-inductor, the magnetic house and the galvanometer, they had succeeded during the 23-minute stop of the boat, in carrying the instruments to a sufficient distance from the steamer to make one pointing on the Sun and one on the mark, three settings of the earth-inductor, one pointing on the magnet, and one on the mark, and one series of observations of 150 oscillations, and to return to the steamer. The values of D, I and H, computed from these observations, gave quite satisfactory results when plotted on the isolinic charts.

Generally the author is of the opinion that the time of every forced stop caused by some unforeseen circumstance must be used for an extension of the above program, as well as to an increase of the number of the observations of each item of the program, or for repeating the observations at another point of the station, or for organizing variometric observations. But if the time of the stop is limited it is better to use it for the determination of two or even one element instead of the three, with the intention of determining at the followng station only the deficient elements, if the stop there also will be short, rather than to make no observations at all. In the practice of his seven expeditions, the author in several cases used a 15 to 20-minute stop of the steamboat for a determination of D and H, or of only D, or of only I, or of only H.

The determination of H can be simplified. The most important step in this direction would be attained if we could eliminate the use of the chronometers, which have to be transported very carefully. Indeed, the modern methods of preparing magnets, the magnetic moment of which decrease very slowly and regularly, make it possible to determine the magnetic moment only at the beginning and at the end of even comparatively long-lasting expeditions and of observing on the expedition either the deflections

only, or the oscillations only, with but an insignificant decrease of the precision of the result.

First steps in this direction were made by V. D. Dudeckij and the author by means of a stop-watch with a double pointer; one was running uninterruptedly, and the second stopped after a first pressing of the button, and at a second pressing of the button overtook the first pointer and went along together with it. The experiments gave quite satisfactory results. Furthermore, the author proceeded to the use of an ordinary watch, by means of which the observer noted the times after counting two seconds after the passage of the magnet. The errors in the notations of the time seldom exceed half a second. If we consider the unfavorable case, that the time of 5 oscillations is only 18 seconds, and that only 150 oscillations are observed, then in using a chronometer and assuming the mean error of the difference of the moments of the passage to be equal to 0.2 second, we obtain for the relative accuracy of the period the value $\frac{0.2}{360\sqrt{11}} = 0.00017$ of the period, that means of 0.03 per cent of H, and in using an ordinary watch, of 0.12 per cent H, e. g., about 25γ for the author's region of work, which may be considered as a sufficient precision.

If we limit outselves to a precision of this kind and agree to take observations of deflections only at the final stations of an expedition, the dimensions of the box containing the magnetometer can be considerably diminished. We do not need the deflection bar, nor the box for the deflecting magnet, nor the deflecting magnet itself; the suspension ribbon can be made shorter and also somewhat thicker, and therefore more solid, and hence the magnet house smaller.

It should be noted that, if in order to increase the number of stations very much, the precision is reduced to $20'$ for D, 100γ for H, and $10'$ for I, the instrumental equipment might be reduced to considerable simplicity and portability. The azimuth could be determined by observation of Polaris without any angle-measuring instrument, for instance, by means of two plumb-lines,[9] which allow finding the direction of the meridian within $10'$ to $15'$. The time-correction of the watch might then be found within 30 to 40 seconds by observing the passage of some known stars.

For the determination of D, a good declination needle could serve, especially when it is provided with a double top. For the determination of H and V (and hence of I) with a precision of ¼ to

½ per cent of their values, the portable "deflectors" used in the navy could serve, giving the values of H and V by means of simple and rapid manipulations. Such a simplification of the method of field observations might extend our knowledge of the distribution of the magnetic elements to regions never before visited, not only by magneticians, but by any scientific investigator.

TOMSK, SIBERIA.

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COMMENTS ON WEINBERG'S SUGGESTIONS FOR FIELD WORK.[1]

By J. A. Fleming.

With modern instruments and reasonable control of secular variation and a scheme of observation arranged so as to aid in the elimination of diurnal variation, it seems assured that the values of the magnetic elements for a given epoch at stations where observations have once been made may be known with an accuracy approaching $\pm 2'$ in declination, D, and inclination, I, and with an accuracy of $\pm 0.001H$ in horizontal intensity, H, with the exception of stations in high magnetic latitudes where diurnal-variation corrections and reductions on account of magnetic storms are uncertain.[2] This should hold even in regions where there are relatively few stations. The real values at points intermediate between stations should be capable of interpolation with a precision not much less than above indicated *provided* no local disturbances exist. It is the practice of the Department of Terrestrial Magnetism, as indicated in our "General Directions for Magnetic Observations," to determine at each station, before carrying out the complete program of observations, whether there is any appreciable local disturbance, thus insuring that distribution and secular-variation stations may represent, as nearly as possible, normal values in the regions concerned. For regions where local disturbances are found to exist, provision is made for a greatly increased number of stations with a lower order of precision.

Multiplicity of relatively inaccurate observations in regions of known distribution, at practically the same expenditure of time and money, would be a mistake, particularly in view of the fact that the secular change, as shown by extensive experience, may not be extrapolated safely for many years. Secular-change data resulting from observations made at intervals of from 20 to 30 years, a procedure indicated as desirable by Weinberg, would not meet requirements.

The extensive experience of our observers in all parts of the world has shown that with the modern form of magnetometers difficulties of transportation can be successfully overcome. For surveys in regions of high magnetic latitude our work has been facilitated, with no great decrease in general accuracy, by the use of the dip circle with compass and telescope attachments, using Lloyd's method for the determination of total intensity, F, and inclination, I, with the restriction that loaded-dip and deflection observations should invariably be made at every station; with this universal instrument it is possible to secure observations for the determination of all three elements in a very short time.

Our practice is to take advantage of every opportunity offered to secure observations, even if only one element can be determined,

Concluded on page 168.

[1] *Cf. Terr. Mag.*, this article, pp. 150-155.

[2] Because of the different order of values of H at various stations, it is desirable to express the order of accuracy of observation in parts of H rather than in gammas, as Weinberg has done.

LATEST ANNUAL VALUES OF THE MAGNETIC ELEMENTS AT OBSERVATORIES.[1]

COMPILED BY J. A. FLEMING.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Sodanklyä . . .	67 22 N	26 39 E	1915	0 27.2 E	75 22.1 N	.12853	.49232[2]
			1916	0 34.6 E	75 25.0 N	.12806	.49222
Pavlovsk	59 41 N	30 29 E	1919	2 35.2 E	71 07.9 N	.16023	.46882
Sitka	57 03 N	135 20W	1920	30 28.2 E	74 22.1 N	.15574	.55663
Katharinenburg	56 50 N	60 38 E	1913	10 57.4 E	71 12.1 N	.17290	.50792
			1914	11 00.1 E	71 16.2 N	.17219	.50786
			1915	11 02.6 E	71 21.2 N	.17142	.50797
			1916	11 03.8 E	71 25.6 N	.17070	.50800
			1917	11 03.7 E	71 29.8 N	.17000	.50796
			1918	11 03.3 E	71 33.7 N	.16936	.50797
			1919	11 02.8 E	71 38.1 N	.16872	.50823
			1920	11 01.9 E	71 42.1 N	.16812	.50843
			1921	11 01.5 E	71 46.1 N	.16754	.50865
Rude Skov . . .	55 51 N	12 27 E	1919	8 07.4W	68 58.2 N	.17144	.44592
			1920	7 57.2W	68 59.6 N	.17124	.44596
Kasan(n.site)	55 50 N	48 51 E	1914[3]	8 21.3 E	69 22.1 N	.17891	.47517
Esdalemuir . . .	55 19 N	3 12W	1919	16 58.7W	69 39.5 N	.16713	.45084
Meanook	54 37 N	113 20W	1921	27 33.3 E	77 53.7 N	.12909	.60190
Stonyhurst . . .	53 51 N	2 28W	1921	15 41.5W	68 43.0 N	.17315	.44449
Wilhelmsh'vn	53 32 N	8 09 E	1911	11 28.2W	67 30.7N[4]	.18110	.43747[5]
Potsdam	52 23 N	13 04 E	1921	7 18.9W	66 34.5 N	.18591	.42911
Seddin	52 17 N	13 01 E	1921	7 20.2W	66 31.5 N	.18629	.42896
Irkutsk	52 16 N	104 16 E	1909	1 51.3 E	70 33.5 N	.19860	.56265

[1]See tables for previous years in *Terr. Mag.*, vol. 4, p. 135; vol. 5, p. 128; vol. 8, p. 7; vol. 12, p. 175; vol. 16, p. 209; vol. 20, p. 131; vol. 22, p. 169; vol. 23, p. 191; vol. 25, p. 179; and vol. 26, p. 147.

[2]The value of Z for 1914 should read 0.49260 instead of 0.49238 as given on p. 147, *Terr. Mag.*, vol. 26.

[3]Values are means for first 4 and last 4 months only.

[4]Absolute values only.

[5]Computed from I and H; the same remark applies wherever values of Z were lacking in observatory publications.

Observatory	Lati-tude	Longi-tude	Year	Declina-tion (D)	Inclina-tion (I)	Intensity	
						Hor. (H)	Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
De Bilt......	52 06 N	5 11 E	1921	11 13.6W	66 52.6 N	.18389	.43065
Valencia[6]....	51 56 N	10 15W	1919	19 27.2W	68 06.1 N	.17842	.44385
Bochum.....	51 29 N	7 14 E	1921	10 10.4W	....	......	......
Greenwich...	51 28 N	0 00	1920	14 08.6W	66 51.8 N	.18456	.43192
			1921	13 57.6W	66 52.0 N	.18449	.43183
Kew........	51 28 N	0 19W	1919	14 40.9W	66 57.7 N	.18416	.43305
Uccle........	50 48 N	4 21 E	1915	12 38.4W	66 01.2N[7]	.18989	......
Hermsdorf...	50 46 N	16 14 E	1913	6 58.2W	....	......	......
Prague.	50 05 N	14 25 E	1914	7 32.1W	....	......	......
			1915	7 24.2W	....	......	......
			1916	7 14.3W	....	......	......
			1917	7 05.3W	....	......	......
Cracow......	50 04 N	19 58 E	1913	5 03.3W	64 18.4 N	......	......
Val Joyeux...	48 49 N	2 01 E	1917	13 21.5W	64 41.2 N	.19690	.41629
			1918	13 12.4W	64 43.2 N	.19680	.41669
Munich......	48 09 N	11 37 E	1911	9 23.8W	63 06.2 N	.20633	.40676
O'Gyalla (Pesth)....	47 53 N	18 12 E	1915	5 50.1W	....	.20995	......
			1916	5 41.1W	....	.20966	......
			1917	5 31.0W	....	.20945	......
			1918	5 21.9W	....	.20917	......
Pola.........	44 52 N	13 51 E	1918	7 11.0W	60 09.0 N	.22113	.38533
Agincourt....	43 47 N	79 16W	1921	6 50.6W	74 44.5 N	.15839	.58065
Tiflis........	41 43 N	44 48 E	1913	3 09.1 E	56 51.1 N	.25217	.37612
Capodimonte	40 52 N	14 15 E	1911	8 05.5W	56 11.7 N	.24171	.36099
			1912	....	56 12.4 N	.24150	.36084
Ebro(Tortosa.	40 49 N	0 31 E	1921	11 49.1W	57 37.6 N	.23301	.36754
Coimbra.....	40 12 N	8 25W	1919	15 29.4W	58 25.0 N	.23075	.37538
Cheltenham..	38 44 N	76 50W	1920	6 18.5W	70 55.4 N	.19118	.55285

[6]Means of 2 absolute values monthly.
[7]Mean of 2 to 4 absolute values each month for 10 months, January to October.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
San Miguel[8] (Ponta Delgada)	37 46 N	25 39W	1913	19 53.2W	60 49.5 N	.23059	.41283
			1914	19 49.4W	60 46.2 N	.23063	.41216
			1915	19 53.2W	60 49.5 N	.23059	.41282
			1916	19 42.7W	60 39.1 N	.23072	.41033
			1917	19 39.2W	60 36.4 N	.23088	.40986
			1918	19 34.1W	60 32.7 N	.23090	.40886
			1919	19 30.4W	60 29.5 N	.23105	.40824
			1920	19 24.9W	60 26.0 N	.23123	.40759
San Fernando	36 28 N	6 12W	1919	14 08.5W	53 44.6N[9]	.25012	......
Kakioka	36 14 N	140 11 E	1914	5 12.9W	49 29.8 N	.29783	.34868
Tsingtau[10]	36 04 N	120 19 E	1916	4 04.7W	52 07.1 N	.30842	.39644
			1917	4 07.0W	52 06.1 N	.30851	.39631
			1918	4 08.2W	52 06.9 N	.30827	.39621
			1919	4 09.9W	52 07.4 N	.30812	.39613
			1920	4 12.9W	52 07.0 N	.30817	.39610
Tucson	32 15 N	110 50W	1919	13 47.8 E	59 27.0 N	.26940	.45644
			1920	13 48.0 E	59 27.6 N	.26910	.45611
Lukiapang	31 19 N	121 02 E	1915	3 13.2W	45 32.1 N	.33212	.33839
			1916	3 16.0W	45 31.9 N	.33201	.33823
			1917	3 17.8W	45 31.5 N	.33201	.33815
			1918	3 18.8W	45 31.0 N	.33212	.33817
Dehra Dun	30 19 N	78 03 E	1920	1 52.0 E	44 59.9 N	.32951	.32949
Helwan	29 52 N	31 20 E	1914	2 09.2W	40 50.9 N	.30016	.25954
			1915	2 03.0W	40 54.8 N	.30012	.26009
			1916	1 53.7W	40 57.5 N	.29985	.26026
			1917	1 45.7W	41 01.9 N	.29963	.26076
Hongkong[11]	22 18 N	114 10 E	1912	0 04.5W	30 56.3 N	.37206	.22302
			1913	0 06.5W	30 53.7 N	.37166	.22239
			1914	0 08.8W	30 53.5 N	.37184	.22247
			1915	0 11.7W	30 52.2 N	.37166	.22217
			1916	0 13.8W	30 51.8 N	.37144	.22198
			1917	0 16.3W	30 50.4 N	.37155	.22183
			1918	0 18.0W	30 48.3 N	.37151	.22150
			1919	0 19.8W	30 47.5 N	.37158	.22143
			1920	0 20.7W	30 46.4 N	.37174	.22137
			1921[12]	0 19.8W	30 45.8 N	.37295	.22199

[8]Means of absolute values as follows, the first figure indicating D and the second figure I and H observations: 1913, 49 and 41; 1914, 37 and 32; 1915, 18 and 12; 1916, 35 and 35; 1917, 44 and 44; 1918, 35 and 35; 1919, 44 and 44; 1920, 28 and 28.

[9]This value is the mean resulting from absolute observations with dip circle and two needles, the individual results showing great and irregular differences.

[10]Values are means from all hourly values.

[11]Values as finally adopted and differing in intensity from those previously published because of changes in distribution-coefficient.

[12]Absolute values at new hut for November and December only; to refer values in new hut to those in the old hut the following corrections must be applied: D, $+3'.0$; I, $-0'.8$; H, -0.00105; Z, -0.00074.

Observatory	Latitude	Longitude	Year	Declination (D)	Inclination (I)	Intensity Hor. (H)	Intensity Ver. (Z)
	° ′	° ′		° ′	° ′	c. g. s.	c. g. s.
Honolulu....	21 19 N	158 04W	1920	9 53.2 E	39 25.1 N	.28847	.23711
Toungoo.....	18 56 N	96 27 E	1920	0 23.7 E	23 07.7 N	.39114	.16707
Alibag.......	18 38 N	72 52 E	1920	0 20.2 E	24 54.7 N	.36922	.17147
			1921	0 15.9 E	24 59.5 N	.36956	.17226
Vieques......	18 09 N	65 27W	1919	3 39.9W	51 17.7 N	.27905	.34825
			1920	3 46.1W	51 22.7 N	.27827	.34831
Antipolo.....	14 36 N	121 10 E	1917	0 35.9 E	16 07.7 N	.38088	.11014
			1918	0 35.5 E	15 05.0 N	.38115	.10986
Kodaikánal...	10 14 N	77 28 E	1920	1 49.9W	4 36.1 N	.37787	.03042
Batavia-Buitenzorg.	6 11 S	106 49 E	1916	0 46.0 E	31 38.4 S	.36698	.22613
St. Paul de Loanda....	8 48 S	13 13 E	1910	16 12.3W	35 32.2 S	.20125	.14374
Apia[13]	13 48 S	171 46W	1921	10 10.7 E	30 03.8 S	.35265	.20412
Tananarivo...	18 55 S	47 32 E	1914	8 25.2W	53 37.9 S	.22484	.30532
Mauritius....	20 06 S	57 33 E	1919	10 10.4W	52 42.8 S	.23112	.30356
			1920	10 20.3W	52 40.1 S	.23093	.30278
Watheroo....	30 18 S	115 53 E	1921[14]	4 22.6W	63 57.7 S	.24848	.50860
Pilar........	31 40 S	63 53W	1918	8 05.5 E	25 39.5 S	.25397	.12200
Toolangi.....	37 32 S	145 28 E	1920	8 00.8 E	67 55.1 S	.22874	.56384
Christchurch[15]	43 32 S	172 37 E	1902	16 15.1 E	67 40.8 S	.22694	.55277
			1903	16 18.3 E	67 42.3 S	.22669	.55286
			1904	16 21.8 E	67 44.1 S	.22644	.55307
			1905	16 25.4 E	67 45.8 S	.22628	.55348
			1910	16 37.6 E	67 54.8 S	.22515	.55485
			1913	16 44.0 E	67 58.2 S	.22449	.55478
			1914	16 44.8 E	67 59.8 S	.22414	.55465
			1920	17 01.7 E	68 09.2 S	.22261	.55525
N. Year's Isl .	54 39 S	64 09W	1916	16 02.4 E	49 39.4 S	.26771	.31520
Orcadas[16]....	60 43 S	44 47W	1912	4 46.5 E	54 26.0 S	.25343	.35442

[13]Formerly designated the Samoa Observatory.
[14]Means of absolute values determined weekly.
[15]Corrected values as finally published or values not previously given in *Terr. Mag.*
[16]Corrected values both for position and for magnetic elements.

ON THE NON-SIMULTANEITY OF MAGNETIC STORMS.

By Rev. Luis Rodés, S. J.

Dr. Bauer in a study based chiefly on data collected by Faris, reached the conclusion that "magnetic storms do not begin at precisely the same instant all over the Earth." The abruptly beginning ones, investigated by him, appeared to progress more often towards the east than towards the west, with a velocity such that it would require, on the average, about four minutes to encircle the Earth at the equator.[1]

I should like to call attention to the fact that in the case of five well-defined storms which occurred subsequent to those examined by Bauer, namely, those of January, February and May, 1919, March, 1920, and May, 1921, I have found a simultaneous beginning at Tortosa and at Honolulu, which lies 158 degrees to the west, within the limits of measurement. The photographic paper at Tortosa runs at the rate of 2.8 minutes to the millimeter and the base line is shown every hour by an electric lamp in connection with the astronomical clock, hence, I do not think we can be in error by a minute. The measures for each storm were accurately made by the writer, and the corresponding times of the beginning as registered at the other stations were kindly communicated to me by Col. E. Lester Jones, director of the U. S. Coast and Geodetic Survey, at Washington, and by Capt. R. L. Faris, acting director.[2]

Table 1 gives the times of beginning of 15 storms in comparison with the times registered at Tortosa. The storm of August 11, 1919, began simultaneously at Lukiapang, Tortosa and Porto Rico, a range of 186 degrees in longitude, while the other stations have apparently registered it progressively earlier.

The last two storms (March 22, 1920, and May 13, 1921) began very suddenly and simultaneously at Tortosa, Cheltenham, Tucson, Sitka and Honolulu, representing a range of 171 degrees.

[1] *Terr. Mag.*, vol. 15, 1910, pp. 221-232; R. L. FARIS, vol. 15, 1910, pp. 93-105; see also L. A. BAUER, vol. 15, 1910, pp. 9-20.

[2] I am indebted to Sir Frederic Stupart for the data of Agincourt; to Prof. J. M. Baldwin for those of Melbourne; to Mr. W. H. Cullum for those of Tucson, and to Rev. J. de Moidrey for information respecting Lukiapang.

It would seem probable that, as the time record has been more accurately kept during recent years, the results would indicate a simultaneous beginning all over the Earth. There are, nevertheless, some cases in which a propagation is strongly suspected. In such cases, which will be the first observatory to register the magnetic storm? I do not know of any answer to this question.

The author has tried a hypothesis which rests to some extent on facts. If a magnetic storm is due to the Earth's entering a cloud of electrical particles projected from the Sun, the case will be similar to that of the Earth's entering the Moon's shadow during an eclipse, and the storm will first be registered at those observatories which are nearer the "front meridian," as I have designated the one which, because of the Earth's rotation, happens to be foremost in direction of movement at the moment the storm begins. (See A, Fig. 1.) Accordingly, an observatory which registers the storm at six o'clock local time should be the first of all to record it; next would follow those nearer to it on either side, and last of all the one at which the storm began at 18^h local time.

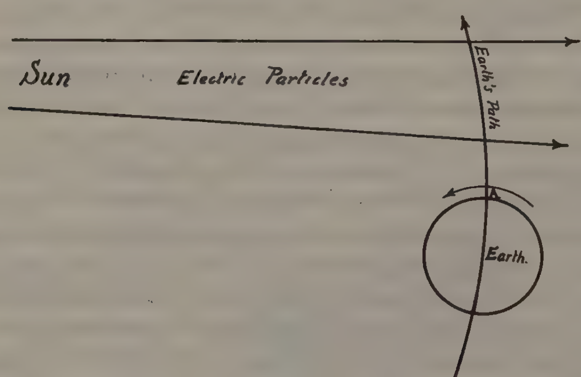

FIG. 1.

As it does not seem possible that a cloud at a distance of 150 million kilometers in free space has an effective transversal velocity greater than 2 kilometers per second, caused by the solar rotation by which it was projected, a rough approximation of the time required for the Earth to become involved in the cloud can be easily obtained from its orbital velocity; this amounts to about six and a half minutes, a little longer than that found experimentally by Bauer. It may be that when half, or even a greater part of the

TABLE 1.—*Greenwich times of beginnings of 15 magnetic storms, and differences as compared with times at Tortosa.**

Number....	Station....(S)	Lati-tude	Longi-tude	12 W.		11 E. ah.		6 E. ah.		5 E. ah.		10 W. ah.		12 W. ah.		11 E. ah.		11 E. ah.	
				1910 Oct. 12-14 18h		1910 Oct. 19 (8)7h		1911 Mar. 20 (5)0h		1914 Jul. 5-6 (6)1h		1914 Oct. 27 16h		1916 Aug. 22 (4)18h		1916 Aug. 25 (7)19h		1917 Aug. 25 (3)19h	
				S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T
		° ′	° ′	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
1	Mel..	37 49 S	144 58 E	30	0	....	....	....	....	....	....	15	−3	30	+3.4	....	....	44	+2
2	Anti .	14 36 N	121 10 E	33	+3	....	....	....	....	....	....	9	(−9)	20	(−6.6)	....	....	34	(−8)
3	Luk..	31 21 N	121 01 E	....	....	....	....	....	....	....	....	14	−4	25	−1.6	....	....	34	(−8)
4	Wath.	30 20 S	116 01 E	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
5	Ali...	18 38 N	12 52 E	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
6	**Tort.**	40 49 N	0 30 E	30	0	13	....	49	....	29.4	....	18	0	26.6	0	44	....	42	0
7	Rico .	18 08 N	65 25W	....	....	....	....	....	....	....	....	17	−1	30	+3.4	....	....	41	−1
8	Chel .	38 44 N	75 50W	....	....	....	....	....	....	....	....	....	....	27	+0.4	....	....	41	−1
9	Tor...	43 39 N	79 23W	27(a)	−3	....	....	....	....	....	....	21	+3	26	−0.6	....	....	30(c)	(−12)
10	Tuc..	32 15 N	110 50W	....	....	....	....	....	....	....	....	....	....	27	+0.4	....	....	41	−1
11	Sit...	57 03 N	135 20W	....	....	....	....	....	....	....	....	21	+3	26	−0.6	....	....	41	−1
12	Hon .	21 19 N	158 03W	....	....	....	....	....	....	....	....	15	−3	26	−0.6	....	....	41	−1
13	Apia .	13 48 S	171 43W	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Sum of residuals, S-Tortosa....					0	....	....	....	....	....	....	....	−14	....	−2.4	....	....	....	−31
Sum, omitting figs. in parentheses					....	....	....	....	....	....	....	....	−5	....	+4.2	....	....	....	−3
Mean deviation from Tort. time					....	....	....	....	....	....	....	....	−0.7	....	+0.5	....	....	....	−0.4

Number....	Station....(S)	0 ah.		12 W. ah.		11 E. ah.		0 ah.		1 W. ah.		3 W. ah.		7 W. ah.		Mean (S-T)
		1917 Sep. 5 (1)6h		1919 Jan. 3 (1)18h		1919 Feb. 27 19h		1919 May 21 6h		1919 Aug. 11 (1)6h		1920 Mar. 22 (1) 9h		1921 May 13 (1)13h		
		S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	S	S-T	
		m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
1	Mel..	5	−3	10	0	25	+1	30	+5	55	−3	8	−2	9	−1	−0.05
2	Anti .	23	(+15)	6	−4	20	−4	13	(−12)	55	−3	10	0	6	−4	−2.0
3	Luk..	10	+2	12	+2	25	+1	25	0	58	0	....	....	....	....	−0.08
4	Wath.	....	....	....	....	....	....	....	....	55	−3	9	−1	9	−1	−1.7
5	Ali...	....	....	....	....	....	....	....	....	....	....	....	....	11	+1	+1.0
6	**Tort.**	8	0	10	0	24	0	25	0	58	0	10	0	10	0	0.0
7	Rico .	9	+1	11	+1	27	+3	23	−2	58	0	10	0	9	−1	+0.3
8	Chel .	8	0	11	+1	26	+2	24	−1	57(9)	−1	10	0	10	0	+0.04
9	Tor...	8	0	10(b)	0	24	+0	....	....	57	−1	9	−1	10	0	−0.3
10	Tuc..	8	0	10	0	25	+1	24	−1	57	−1	10	0	10	0	−0.2
11	Sit...	8	0	11	+1	26	+2	25	0	56	−2	10	0	10	0	+0.2
12	Hon .	7	−1	10	0	24	0	24	−1	57	−1	10	0	10	0	−0.8
13	Apia .	....	....	....	....	....	....	....	....	....	....	....	....	9	−1	(−1)
Sum of residuals, S-Tortosa....		....	+14	....	+1	....	+6	....	−12	....	−15	....	−4	....	−7	
Sum, omitting figs. in parentheses		....	−1	....	+1	....	+6	....	0	....	−15	....	−4	....	−7	
Mean deviation from Tort. time		....	−0.1	....	+0.1	....	+0.6	....	0	....	−1.4	....	−0.4	....	−0.6	−0.30

(1) Very definite in *H*, *Z* and *D*. (3) The peak in *H* and *Z* at the beginning. (4) Very definite in *H* and *Z*; *D* 3 min. later. (5) Very definite in *H*. (6) Very definite in *H* and *Z*. (7) Very definite in *H*, *Z* and *D*. (8) Very definite in *H*. (9) This value was communicated by letter; the value given in *Terr. Mag.*, Sept., 1919, by Geo. Hartnell is 58m. a. Indefinite beginning value for *H*. b. In *H*. c. Uncertain.

*In the first row of this table is given for each storm the position of the "front meridian," as defined by the author in the text; *ah.* stands for "ahead."—*Ed.*

TABLE 2.—*Times of sudden beginnings of magetic storms, 1906-09.*

Date	Mag. El.	Porto Rico		Chel-tenham		Bald-win		Sitka		Hono-lulu		Merid-ian ahead	Time-Differences (n-1)				Sum	
		m	n	m	n	m	n	m	n	m	n		m	m	m	m	m	
1906 Jul. 29	D	....		56.0	(4)	54.4	(3)	55.4	(2)	54.9	(1)	11 E	+0.5	−0.5	+1.1	.....	+1.1	
19^h	H	58.1	(5)	57.8		54.4		55.4		54.9			+0.5	−0.5	+2.9	+3.2	+6.1	
	Z	....		58.1		55.6		58.4		54.0			+4.4	+1.6	+4.1	.....	+10.1	
Aug. 7	D	....		39.3	(2)	39.3	(1)	38.6	(3)	39.9	(5)	7W	0.0	.....	−0.7	+0.6		–
13^h	H	37.2	(2)	39.9		38.7		37.1		37.8			+1.2	−1.5	−1.6	−0.9		–
	Z	....		....		42.3		38.6		39.0			.....	.....	−3.7	−3.3		–
Dec. 21	D	34.5	(5)	31.1	(4)	33.1	(3)	29.3	(1)	30.3	(1)	9 E	.....	+3.3	+1.3	+4.7	+9.3	
21^h	H	34.5		32.0		32.5		26.9		27.3			.....	+5.4	+4.9	+7.4	+17.7	
	Z	33.9		35.3		35.5		30.2		29.1			.....	+5.9	+5.7	+4.3	+15.9	
1907 Feb. 9	D	14.3	(3)	14.0	(2)	15.2	(1)	12.3	(2)	10.4	(1)	8W	−0.5	+1.2	+1.5	.....	+2.2	
14^h	H	12.8		13.4		14.3		11.4		11.9			−1.7	+0.3	−0.3	.....		–
	Z	14.6		16.4		18.2		12.9		16.4			−4.4	−0.9	−2.7	.....		–
Jul. 10	D	24.4	(3)	23.6	(2)	24.4	(1)	22.5	(2)	21.8	(1)	8W	−0.6	+0.5	+1.3	.....	+1.2	
14^h	H	24.7		24.2		22.6		22.2		20.9			+0.5	+2.5	+3.0	.....	+6.0	
	Z	25.6		25.4		25.0		24.6		25.8			−0.8	0.0	+0.2	.....		–
Oct. 13	D	45.4	(1)	42.3	(2)	41.8	(3)	40.2	(4)	41.8	(5)	2W	−3.1	−3.6	−5.2	−3.6		–
7^h	H	42.4		44.1		43.6		40.2		41.5			+0.7	+1.2	−2.2	−0.9		–
	Z	44.5		47.7		....		42.6		45.7			+3.2	.....	−1.9	+1.2	+2.5	
1908 Mar. 26	D	40.5	(4)	42.6	(4)	....	(3)	....	(2)	42.4	(1)	11W	.....	.....	+0.2	−1.9		–
17^h	H	39.4		40.2		42.0		....		42.3			.....	−0.3	−2.1	−2.9		–
	Z	43.8		44.1		45.8		....		45.9			.....	−0.1	−1.8	−2.1		–
Aug. 19	D	10.0	(4)	15.0	(3)	14.0	(2)	14.9	(1)	14.7	(1)	6 E	−0.8	+0.2	−4.8	.....		–
0^h	H	14.2		14.4		14.0		14.6		14.7			−0.6	−0.2	−0.4	.....		–
	Z	16.0		....		....		16.4		18.7			.....	.....	−1.5	.....		–
Sept. 11	D	21.7	(1)	21.0	(2)	20.3	(2)	22.2	(3)	22.1	(5)	1W	−0.7	−1.4	+0.5	+0.4		–
7^h	H	20.8		20.9		20.7		20.2		21.5			+0.1	−0.1	−0.6	+0.7	+0.1	
	Z	23.2		23.1		23.7		22.9		24.5			−0.1	+0.5	−0.3	+1.3	+1.4	
Sept. 11	D	49.2	(5)	46.4	(4)	44.5	(3)	47.8	(2)	45.4	(1)	9W	+2.4	−0.9	+1.0	+3.8	+6.3	
21^h	H	48.0		46.7		48.1		47.5		46.9			+0.6	+1.2	−0.2	+1.1	+2.7	
	Z	50.7		49.1		49.6		48.7		48.1			+0.6	+1.5	+1.0	+2.6	+5.7	
Sept. 28	D	42.7	(1)	43.0	(2)	41.5	(2)	42.5	(3)	42.1	(3)	3W	+0.3	−1.2	−0.2	−0.6		–
8^h	H	41.5		43.6		41.2		41.3		42.4			+2.1	−0.3	−0.2	+0.9	+2.5	
	Z	44.2		46.0		....		45.5		42.9			+1.8	.....	+1.3	−1.3	+1.8	
Sept. 29	D	34.0	(5)	34.3	(3)	31.4	(2)	....	(1)	30.9	(1)	5W	+0.5	+3.4	.....	+3.1	+7.0	
1^h	H	31.9		33.4		31.4		....		30.0			+1.4	+3.4	.....	+1.9	+6.7	
	Z	34.3		34.3		33.2		....		31.5			+1.7	+2.8	.....	+2.8	+7.3	
1909 May 14	D	56.4	(1)	57.2	(1)	57.7	(2)	58.0	(3)	54.0	(5)	1 E	+0.9	+1.2	.....	−2.8		
4^h	H	54.3		57.2		56.8		53.7		53.1			+1.1	−2.0	.....	−2.6		
	Z	58.4		58.3		60.7		60.7		56.4			+2.3	+2.3	.....	−2.0	+2.6	
Sept. 25	D	39.8	(1)	41.5	(2)	39.3	(2)	40.3	(3)	42.7	(5)	3W	+1.7	−0.5	+0.5	+2.9	+4.6	
8^h	H	37.7		40.9		38.7		39.5		42.7			+3.2	+1.0	+1.8	+5.0	+11.0	
	Z	38.6		....		42.3		42.2		....			+3.7	+3.6	.....	.....	+7.3	
Sept. 25	D	39.8	(1)	42.1	(2)	40.8	(2)	42.2	(3)	46.3	(5)	6W	+2.3	+1.0	+2.4	+6.5	+12.2	
11^h	H	39.8		43.3		41.1		39.8		45.4			+3.5	+1.3	0.0	+5.6	+10.4	
	Z	41.0		45.1		41.1		....		49.0			+4.1	+0.1	.....	+8.0	+12.2	
												Sums	+33.0	+31.4	+4.3	+43.1	+173.9	

Earth, is immersed in the electric cloud, induction phenomena are produced which advance the time of beginning at the other stations.

The writer has tried to ascertain whether this explanation is supported by facts and for this purpose has rearranged the data collected by R. L. Faris as given in Table 2.[3] To each station is assigned a number indicating the order of succession for the registration of each storm, according to the "front meridian" given in the eighth column; when the distance of two stations from the "front meridian" was practically equal, the same number has been given and the mean of their distances is used. In the ninth column are given the differences, second station minus first, third minus first, etc. Now, according to the hypothesis under consideration, these differences should be positive, and the results of Table 2 seem to favor this conclusion since the sum of all the differences is positive in each case, and the general positive mean is about three times greater than the negative one.

In order to obtain more definite results I have taken only the two stations, Cheltenham and Honolulu, which are separated by about 82 degrees of longitude; the first column of Table 3 gives the "front meridian" at the time of beginning and the stations are

TABLE 3.—*Comparison of recorded times of magnetic storms, 1906-1909, at Honolulu and Cheltenham.*

Front Merid.	Date	Hour	Honolulu	Cheltenham	b−a, or a′−a	
		h	m	m	m	m
XI E	1906, Jul. 29	19	54.6 a	57.3 b	+ 2.7	
VII W	Aug. 7	13	38.9 a	40.3* a′	+ 1.4	
IX E	Dec. 21	21	28.9 a	32.8 b	+ 3.9	
VIII W	1907, Feb. 9	14	12.9 a	14.6 a′	+ 1.7	
VIII W	Jul. 10	14	22.8 a	24.4 a′	+ 1.6	
II W	Oct. 13	7	43.0 b	44.7 a		− 1.7
XI W	1908, Mar. 26	17	43.5 a	42.3 b		− 1.2
VI E	Aug. 19	0	16.0 a	15.4* a′		− 0.6
I W	Sept. 11	7	22.7 b	21.7 a	+ 1.0	
VIII E	Sept. 11	21	46.8 a	47.4 b	+ 0.6	
III W	Sept. 28	8	42.5 b	44.2 a		− 1.7
V E	Sept. 29	1	30.8 a	34.0 b	+ 3.2	
II E	1909, May 14	4	54.5 a′	57.6 a		− 3.1
II W	Sept. 25	8	43.4* b	41.9* a	+ 1.5	
V W	Sept. 25	11	46.9 b	43.5 a	+ 3.4	
				Sum...	+21.0	− 8.3

*In deriving these quantities, the author appears to have used some method for supplying missing data in Table 2.—*Ed.*

[3]See GIUSEPPE GIANFRANCESCHI, S. J., "Velocità istantanea della Terra," Roma, *Mem. Acc. Nuove Lincei*, Ser. 2, vol. 4.

marked a or b (a, a', if the difference is negligible), according to their distance from it. Here again the sum of the positive differences b-a is nearly three times as large in absolute value as the sum of a-b.

There are still some very conspicuous exceptions to the rule given, but the agreement is close enough to justify further investigation of the subject.

It is also possible that some of the electric clouds are of cosmic character and have their own velocities. The movement of the whole planetary system, through space and the angle which the direction of the instantaneous apex[4] makes with the Sun-Earth line, might affect the results for such cases. It would be very desirable, were it possible, to compare the beginning of magnetic storms on different planets, but as there is no hope, for the present at least, of obtaining records of such storms, experienced on Jupiter or on Saturn, for example, we must confine our investigations to our own Earth, collecting as many carefully-recorded data as possible.

OBSERVATORIO DEL EBRO,
TORTOSA, SPAIN.

[4]See footnote 1.

LETTERS TO EDITOR

PROVISIONAL SUN-SPOT NUMBERS FOR JULY TO SEPTEMBER, 1922.[1]

Day	July	Aug.	Sept.	Day	July	Aug.	Sept.
1	0	0	6	18	0	0	7
2	0	0	..	19	..	0	8
3	0	7	0				
4	0	7	0	20	28	0	7
5	15	7	0	21	22	0	8
6	24	15	0	22	28	0	7
7	19	8	6	23	..	..	8
8	29	0	..	24	19	17	7
9	..	0	..	25	20	..	0
				26	13	..	0
10	16	0	..	27	7	23	7
11	7	0	0	28	7	16	7
12	7	0	..	29	0	19	..
13	0	0	8				
14	0	0	12	30	0	14	8
15	..	0	..	31	0	15	
16	0	0	7				
17	0	0	7	Means	9.7	5.3	5.2

A. Wolfer.

[1]For previous table, see *Terr. Mag.*, **27**, 120, 1922.

EARTHQUAKE RECORDS, WATHEROO MAGNETOGRAMS, NOVEMBER, 1921.

There was a record of an earthquake on the magnetograms of the Watheroo Magnetic Observatory, Western Australia, on November 11, 1921. The declination and horizontal-intensity traces showed a slight broadening, while there was a very slight blurring of the vertical-intensity trace. The extreme Greenwich mean times of the record were from $18^h\ 45^m$ to $19^h\ 01^m$ for declination, $18^h\ 44^m$ to $18^h\ 56^m$ for horizontal intensity, and $18^h\ 52^m$ to $18^h\ 59^m$ (uncertain) for vertical intensity. Mr. Curlewis, Government Astronomer at Perth, reported the following times of phases as obtained on the seismograph: $18^h\ 43^m\ 56^s.6$, *P;* $18^h\ 46^m\ 00^s.5$, uncertain; $18^h\ 50^m\ 10^s.4$, *L.*

G. R. Wait, *observer-in-charge.*

EARTHQUAKE RECORDS, HUANCAYO MAGNETOGRAMS, OCTOBER-NOVEMBER, 1922

The details of the records, as measured on the magnetograms of the Huancayo Magnetic Observatory, Peru, are as follows, the times indicated being Greenwich civil mean time:

1. *October 11, 1922.*

Magnetic Element	Beginning		End		Maximum amplitude
	h	m	h	m	mm.
Declination	14	51	14	55	2.0
Horizontal intensity	14	52	14	56	2.5
Vertical intensity	14	52	14	56	2.5

This earthquake was recorded also on the seismograph of the Harvard College Observatory, at Arequipa, Peru. Some damage was done to property in the neighborhood of Arequipa, and a few persons were injured.

2. *Great Chilean Earthquake.*

The Chilean earthquake effect was recorded at Huancayo only on the vertical-intensity magnetogram, the effect beginning at G. M. T. $4^h\ 35^m$ and ending at $5^h\ 15^m$, November 11, 1922; the maximum amplitude of the effect was about 1.0 mm. at $4^h\ 45^m$.

W. F. Wallis, *observer-in-charge.*

COMMENTS ON WEINBERG'S SUGGESTIONS FOR FIELD WORK.

Concluded from page 156.

and it has frequently happened that determinations of the three elements have been made within an hour's time. In every case, however, when partial observations are made because of scant time available, the constancy of the magnetic moment for the magnetometer-magnet and of the relative constants involved in the total-intensity observations are controlled by complete sets of observations at preceding and succeeding stations.

As regards the matter of timing of oscillations, the half-second pocket chronometer has been found sufficiently reliable in our field practice. Several attempts have been made to use stop watches for such work, but without very satisfactory results. The suggestion that the determination of plane of detorsion be omitted is subject to criticism since such procedure would introduce a great element of uncertainty in the determination as, for example, the accidental accumulation of 180° or 360° of torsion through rotation of the suspension stirrup. It seems inadvisable also to use shorter or coarser suspensions for magnetometers in declination work since it has been found in actual experience that observers may use for periods of from one to two years in the field the same light-weight fiber with a torsion effect which is small.

INVESTIGATION OF LOCAL MAGNETIC DISTURBANCES AT PORT SNETTISHAM, ALASKA.

By N. H. Heck.

The United States Coast and Geodetic Survey is now carrying on its work in Alaska primarily by large parties, each using a vessel and several large launches to carry on all the operations necessary to a complete survey. The magnetic work included is at present confined to compass-declinometer observations on shore and to declination observations aboard ship made chiefly in areas of local disturbances.

The adoption of steel vessels on the one hand and the vastly more satisfactory observations obtained on a non-magnetic vessel such as the *Carnegie*, however, have made the continuance of observations on the Coast and Geodetic Survey vessels of doubtful desirability, except in special cases.

Areas of local disturbances may be known from previous surveys, or as the result of obtaining compass-declinometer observations at triangulation stations along the shores at an average distance of about two miles.

The area of Port Snettisham, Alaska, was known to be highly disturbed, but no detailed facts were available. Recent commercial developments, which required large vessels to enter this port, made a magnetic survey of considerable importance. The diagram (Fig. 1) brings out the results of the survey, though it fails to show that observations were made at 34 shore stations and 111 sea stations by the party on the United States Coast Survey Steamer *Explorer*. The depth of water is shown in feet. Reference to the scale of statute miles indicates the considerable extent of this area. The curves shown represent the departure of the declination from the normal values, the plus sign indicating easterly and the minus sign westerly departures.

Unfortunately, owing to the lack of time and the dense forest, it was impossible to investigate the existence of a local magnetic pole. The outstanding feature in this case is the extension of great local disturbance into areas of great depths. It will be noted that the 20° curve extends ¾ of a mile from the shore into a maximum depth of 772 feet.

The methods used in making the survey are of particular interest; the standard practice of the Coast and Geodetic Survey in hydrographic work was followed. Plane table triangulation was extended from the entrance of Port Snettisham to the shore indicated on the eastern side of the diagram and also into the south arm. Stations were temporarily marked by small signals and white-wash on the rocks; intermediate points were marked by white-wash or small flags, but no signals were built, in order to avoid confusion.

Each shore station was occupied with compass declinometer, the true azimuth of some other station being obtained from the results of the plane table triangulation. It was found necessary, owing to the rapid change in the dip, to shift the balancing weight on the south arm of the compass needle at nearly every station.

The methods used aboard ship were adapted to getting rapid observations. A system of lines was run just as in hydrography, the vessel proceeding at a speed of about six miles an hour. As the compass could not be used for keeping the vessel to its path, the method of steering for a point ahead on the land was adopted. Three-point fixes were taken at two or three-minute intervals, according to conditions. These were followed immediately by taking the compass bearing of one of the shore stations, preferably one nearly ahead or astern. The ship's head by compass was noted at the same instant. As the observers were skilled, the whole observations were practically simultaneous; the three-point fixes were plotted to direct the course of the vessel, but no effort was made to measure the azimuth until later.

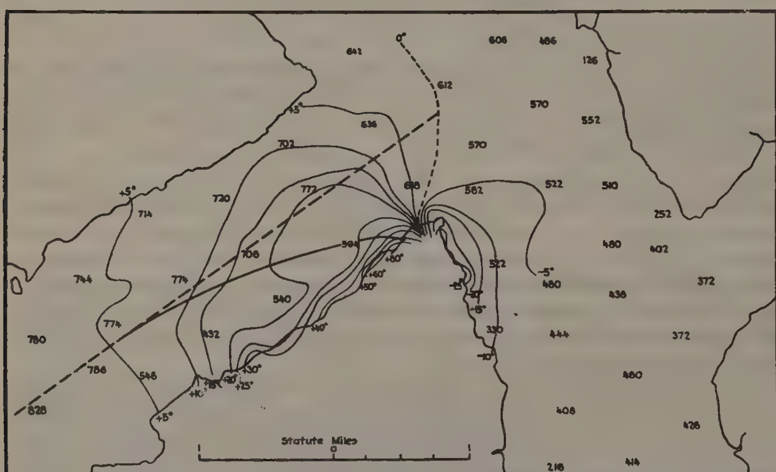

Fig. 1.—Area of marked local disturbance at Port Snettisham, Alaska, about 50 miles south of Juneau.

(The heavy broken line is path of vessel following mid-channel compass course, if there were no local disturbance. The heavy line is path taken by the same vessel steering in the same compass course as on entering.)

The compass deviations were obtained from swings in an undisturbed region; they were comparatively small, but were used to correct all compass bearings. All crossings check within half a degree, even where the amount of disturbance was considerable. The behavior of the compass on a close inshore line parallelling the south shore is of great interest. In proceeding from the entrance

to Port Snettisham, the compass was first affected at a distance of about three miles from Sentinel Point; it gradually swung to the eastward of magnetic north until it pointed 41° east of magnetic north, it then suddenly spun around to a position 15° west of magnetic north, and then gradually came back to normal.

This is by no means the first investigation of such an area. Another notable instance is that at Douglas Island, near Juneau, where Dr. L. A. Bauer in 1907 found a local magnetic pole. The investigations of H. M. S. *Penguin*[1] were of a similar character, though the disturbed area was entirely submerged and the area was less. An investigation of a similar character to that described has been recently made in Chilkat and Chilkoot Inlets, Lynn Canal, Alaska, but the results are not yet available.

The geological character of a region of such marked magnetic disturbance, as the one at Port Snettisham, is of great interest, especially since the area involved is by no means small. It is estimated that the disturbance is strong over an area of eight square miles of land and water, and is felt over an area of 20 square miles. Rocks along the shore indicate the presence of considerable magnetite. In view of the fact that the local magnetic pole on Douglas Island is not far from the well-known Treadwell gold mine, it may be of some interest to point out that there are also gold mines in the vicinity of Port Snettisham. An extended investigation would probably be necessary to determine the exact manner in which the iron appears and whether there are deposits of commercial value.

U. S. Coast and Geodetic Survey,
Division of Terrestrial Magnetism.

[1]London, *Phil. Trans. R. Soc.*, A, v. 187, 1896 (345-381).

NOTES

22. *Principal Magnetic Storms at Cheltenham Magnetic Observatory, July to December, 1922.*[1]

[1]Communicated by E. Lester Jones, director, U. S. Coast and Geodetic Survey: Geo. Hartnell, observer-in-charge; Lat. 38° 44′.0 N; Long. 76° 50′.5, or 5 h 07.m4 west of Greenwich.

Greenwich Mean Time		Range		
Beginning	Ending	Decl'n	Hor'l Int.	Vert'l Int.
h m	h m	′	γ	γ
Sept. 13, 3 24	Sept. 15, 5 ..	30.4	179	232
Oct. 5, 2 ..	Oct. 7, [illegible] ..	32.5	193	92

23. *Erratum, General Report of Rome Meeting, International Section of Terrestrial Magnetism and Electricity.*—In the French translation of Resolution 4, as given on p. 99 of *Terr. Mag.*, vol. 27, or on p. 11 of "Bulletin No. 2," 9 important concluding words were omitted. The resolution should read:

4. Que les Comités Nationaux soient priés de désigner, s'il est possible, un

observatoire central pour leurs pays respectifs, chargé des comparaisons internationales des instruments magnétiques, et d' assurer dans leurs propres pays une comparaison des instruments magnétiques au moins une fois tous les trois ans.

24. *Second Pan-Pacific Scientific Congress and the Australian National Research Council.*—The Australian National Research Council has fixed the date of the Second Pan-Pacific Scientific Congress as August 13 to September 3, 1923. The first session is to be held at the University of Melbourne, and the second session (August 21 to September 3), at the University of Sydney. Excursions are planned as part of the congress program and, after adjournment of the formal meeting, there will be opportunities for visits to other parts of the continent. The Australian Federal Government has made a liberal grant for meeting the necessary expenses. We regret to learn that, owing to a severe illness arising from a wound received during the war in France, *Sir T. W. Edgeworth David* has resigned his position as president of the Australian National Research Council. His place, however, has been ably filled by the election of *Dr. Orme Masson*, professor of chemistry in the University of Melbourne. Professor David continues to serve the council as vice-president.

25. *Amundsen Arctic Expedition, 1922.*—According to information received from the Chief of the United States Weather Bureau, Professor C. F. Marvin, wireless reports of meteorological observations made aboard the *Maud* came intermittently until August 17, then nothing was received until September 28, 1922, when ten reports came in; nothing has been received since then. The geographic position of the *Maud* when the last report was received (September 28) was: Latitude, 73°N., longitude, 176°W., hence, about 100 miles north of Wrangell Island. According to newspaper reports, Captain Amundsen arrived on December 14, by dog-team, at Nome, Alaska, from Wainwright, near Point Barrow, where he is wintering. [As the Journal is passing through the press, a wireless message of December 15 has been received *via* the radio station at Spitsbergen from Capt. Wisting, aboard the *Maud*, in lat. 73° 20′ N., long. 173° W. (? E.).]

26. *Personalia.* — Prof. *G. Hellmann* has retired from the post of director of the Prussian Meteorological Institute, which he had filled so successfully since von Bezold's death. Dr. *E. Marsden* has resigned his professorship of physics in the Victoria University College at Wellington, in order to accept the post of Assistant Director of Education in the New Zealand government service. Dr. *Robert A. Millikan* has been appointed a member of the Committee on Intellectual Cooperation of the League of Nations to succeed Dr. George E. Hale, who has resigned from the committee. A royal medal has been awarded by the Royal Society of London to *C. T. R. Wilson* for his researches on the condensation nuclei and atmospheric electricity. The Paris Academy of Sciences awarded the Janssen medal to *Carl Störmer* for his investigations of the aurora. We regret to record the death, on September 27, of Prof. *C. Michie Smith*, government astronomer of Madras, 1891-1911, and director of the Kodaikanal and Madras Observatories, 1899-1911.

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ANGENHEISTER, G., AND C. J. WESTLAND. The magnetic storm of May 13-14, 1921: Observations at Samoa Observatory. Wellington, N. Z. J. Sci. Tech., v. 4, No. 4, 1921 (201-202). [*Cf.* Terr. Mag., v. 26, 1921 (30-31).]

AULT, J. P. Sailing the seven seas in the interest of science. Adventures through 157,000 miles of storm and calm, from Arctic to Antarctic and around the world, in the non-magnetic yacht "Carnegie." Nation. Geog. Mag., Washington, D. C., Dec., 1922 (631-690 with illus.).

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CHRISTCHURCH MAGNETIC OBSERVATORY. Hourly values of the magnetic declination and the horizontal magnetic force for the years 1910 and 1920. By H. F. Skey, Director. Wellington, Marcus F. Marks, Govt. Printer, 1921 (24). 34 cm.

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HAUSSMANN, K. Uebersichtskarte der magnetischen Deklination in Deutschland mit der Epoche 1921 (Jahresmitte). Petermanns geogr. Mitt., Gotha, 68. Jahrg., 1922 (178-180 mit 1 Karte).

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